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XXI. *On the Annual and Semi-Annual Seismic Periods.*

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Communicated by Professor J. H. POYNTING, *F.R.S.*

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1. IN 1834 the existence of an annual period of earthquake frequency was pointed out by MÉRIAN, and his discovery has been fully confirmed by the work of later seismologists. No result of equal importance was, however, added to our knowledge until fifty years afterwards, when a valuable memoir* was presented by Dr. C. G. KNOTT to the Seismological Society of Japan. As the present paper follows somewhat closely in the lines laid down by Dr. KNOTT, I will first give a short account of the results obtained by him, and in the next section will describe his method of investigation.

One of the objects of DR. KNOTT's work was to ascertain whether any trace could be detected of a six-monthly, as well as of an annual, period. He examined for this purpose lists of earthquakes in Japan from 1872 to 1880 (MILNE), Europe and the adjacent parts of Asia and Africa from 306 to 1843 (PERREY), the Grecian Archipelago from 1859 to 1873 (SCHMIDT), the East Indian Archipelago from 1873 to 1881 (BERGSMA), New Zealand from 1869 to 1879, and Chili from 1873 to 1881 (VERGARA). The chief results obtained from this discussion are the following: (1) In five of the six districts selected there is a well-marked annual period, the maximum occurring about December or January in Europe, the Grecian Archipelago, and Japan, and between June and September in New Zealand and Chili; *i.e.*, during the winter season in every case: while in the East Indies, lying close to and on either side of the equator, no such period could be discerned. (2) With the exception again of the East Indies there seems to be in the earthquakes of each district a semi-annual period, the maxima occurring about January† and June or July in Europe, about March and September in the Grecian Archipelago, about June and November in Japan, about February and August in New Zealand, and about April (for the first maximum) in Chili, the second not being clearly defined. In the case of Europe, the semi-annual period is not very pronounced, and the smoothness of the curve representing it as

* "Earthquake Frequency" [1884], 'Japan, Seismol. Soc. Trans.,' vol. 9, part 1, 1886, pp. 1–20.

† These dates differ from those given by Dr. KNOTT. The reason for the change is stated below in § 3.

compared with the others "almost suggests," says Dr. KNOTT, "that this semi-annual characteristic is almost accidental, and that with a sufficient number of observations it might vanish altogether"; "and yet," he adds, "it seems too general to be accidental."

It appears to me, therefore, desirable to examine the seismic records of other countries besides those which were at the disposal of Dr. KNOTT in 1884, and this I shall endeavour to do in the present paper. The relation of seismic periodicity to intensity will also be considered, though the materials are somewhat inadequate for the purpose. In the closing paragraphs, a summary is given of the principal conclusions arrived at, and an attempt is made to show that the annual variation in barometric pressure may be the cause of the annual seismic period.

With regard to the origin of the semi-annual period, I regret that I am unable to offer any definite suggestion.

METHOD OF INVESTIGATION.

2. *Dr.* KNOTT's *Method.*—If $f(\theta)$ be a periodic function of a variable θ, we may write

$$f(\theta) = a_0 + a_1 \cos(\theta + \alpha_1) + a_2 \cos(2\theta + \alpha_2) + \ldots + a_n \cos(n\theta + \alpha_n) + \ldots,$$

from which it follows that

$$\frac{1}{2\phi}\int_{\theta-\phi}^{\theta+\phi} f(\theta)\,d\theta = a_0 + \frac{a_1 \sin\phi}{\phi}\cos(\theta + \alpha_1)$$
$$+ \frac{a_2 \sin 2\phi}{2\phi}\cos(2\theta + \alpha_2) + \ldots + \frac{a_n \sin n\phi}{n\phi}\cos(n\theta + \alpha_n) + \ldots;$$

the latter equation giving the mean value of $f(\theta)$ through an interval ϕ on either side of θ.

Let T and S be the values of the last series when ϕ is put equal to $\pi/4$ and $\pi/2$ respectively, then

$$\mathrm{T} = a_0 + \frac{2\sqrt{2}a_1}{\pi}\cos(\theta + \alpha_1) + \frac{2a_2}{\pi}\cos(2\theta + \alpha_2) + \ldots$$
$$+ \frac{4a_n \sin\frac{1}{4}n\pi}{n\pi}\cos(n\theta + \alpha_n) + \ldots,$$

$$\mathrm{S} = a_0 + \frac{2a_1}{\pi}\cos(\theta + \alpha_1) - \frac{2a_3}{3\pi}\cos(3\theta + \alpha_3) + \ldots$$
$$+ \frac{2a_n \sin\frac{1}{2}n\pi}{n\pi}\cos(n\theta + \alpha_n) + \ldots,$$

and

$$S - \frac{T}{\sqrt{2}} = a_0\left(1 - \frac{1}{\sqrt{2}}\right) - \frac{a_2\sqrt{2}}{\pi}\cos(2\theta + \alpha_2) + \ldots$$
$$+ \frac{2a_n}{n\pi}(\sin \tfrac{1}{2}n\pi - \sqrt{2}\sin \tfrac{1}{4}n\pi)\cos(n\theta + \alpha_n) + \ldots;$$

where in T all terms are absent which involve multiples of 4θ, in S all those involving multiples of 2θ, while, in the third expression, the terms involving θ and all multiples of 4θ disappear.

If, then, we take 2π to represent a period of one year, T represents the result of taking three-monthly means, and the effect of this is to eliminate the three-monthly period, if there be one, and all periods which are fractions of three months, and also to diminish the amplitudes of all other periods relatively to that of the annual period. In like manner, S represents the result of taking six-monthly means, the effect being to eliminate the six-monthly period, if there be one, and all periods which are fractions of six months, and also to diminish the amplitudes of all other periods relatively to that of the annual period. The result of the third operation is to eliminate the annual period, and to give special prominence to the six-monthly and four-monthly periods, if such exist.

Now, if we have a record of all the earthquakes felt during a given interval (containing an exact number of years) over a definite area, and if we group together all the earthquakes felt during each month of the year, we may regard the numbers so obtained as representing the average number for each month felt on the middle day of that month. The mean of the numbers for the months of December, January, and February, will be the three-monthly mean corresponding to the middle of January; and the mean of the numbers for the months of November, December, January, February, March and April, will be the six-monthly mean corresponding to the end of January. If three-monthly and six-monthly means be calculated in this manner for each month, and if the results be plotted in the usual way, the first of the curves so obtained will show no trace of a three-monthly period, and the second none of a six-monthly period. To eliminate the annual period, arithmetic means are interpolated between each pair of numbers in the two series, the means of the first series giving the three-monthly means corresponding to the end of each month, and those of the second series the six-monthly means corresponding to the middle of each month. Multiplying each number of the first series by $1/\sqrt{2}$, or ·707 . . . , and subtracting it from the corresponding number of the second series, the curve obtained by plotting the resulting differences will show no trace of an annual period, and will give special prominence to the six-monthly and four-monthly periods, if such exist. Lastly, if each of the twenty-four differences be divided by the average of all, the curves so obtained for different intervals and for different areas of observation will be more directly comparable with one another.

3. If the third and succeeding terms in the expression for $S - T/\sqrt{2}$ may be neglected in comparison with the first and second, it is evident that $S - T/\sqrt{2}$ will be a maximum when the second term (which determines the six-monthly period) is a minimum, and *vice versâ*. By a slight oversight, Dr. KNOTT has reversed the sign of this term, and consequently the epochs which he obtains for the maxima of the six-monthly period are in reality those of the minima, and *vice versâ*.

4. *Method adopted in this Paper.*—I have described in some detail the method employed by Dr. KNOTT, for, in principle, it is the same as that adopted in this Paper. The chief differences are that I have used the same method in investigating both the annual and semi-annual periods,* and have also taken into account the variable length of the month.

Whenever possible I have grouped the earthquakes in half-monthly, instead of in monthly intervals, the first half of February containing fourteen days, and of all other months fifteen days. The numbers so obtained are then reduced to equal half-monthly intervals of fifteen days.

In investigating the annual period, the reduced figures for the halves of each month are added together, giving the numbers of earthquakes corresponding to equal monthly intervals of thirty days. Six-monthly means are then taken of these numbers, as in Dr. KNOTT's method, and the mean thus obtained for the end of each month is divided by the average of all twelve means.

For the semi-annual period, the reduced figures for the first half of January and the first half of July are added together, and so on. Six-half-monthly means are then taken of these numbers, and the mean thus obtained for the end of each half-month is divided by the average of all twelve means.

5. Seismologists generally group earthquakes in monthly intervals, and in some cases I have only been able to make use of such tables. In a few others, also, for reasons which will be obvious, I have used them though having access to the catalogues on which they were founded. The results obtained in this way are not of equal value for purposes of comparison, as they probably depend on different definitions of the unit earthquake.

In all these cases the monthly numbers are first reduced to equal intervals of thirty days. The discussion for the annual period is then continued as before.

For the semi-annual period the numbers for January and July are added together, and so on. Three-monthly means are then taken of these six numbers, and the mean thus obtained for the middle of each month is divided by the average of all six means. The method, of course, chiefly differs from the preceding in giving fewer points upon the curve.

6. Again, in taking six-monthly means for the annual period, and dividing each by the average of all twelve, it is evident, from the expression for S in § 2, that every

* In investigating the semi-annual period by this method, it is obvious that the annual period is eliminated (see § 10).

ordinate in the curve so obtained is reduced in the ratio $2:\pi$. It is also further reduced by the method of grouping the earthquakes in monthly intervals. For, instead of using the actual ordinate for $\cos\theta$, we use the average ordinate over an interval $\pi/6$, that is

$$\frac{6}{\pi}\int_{\theta-\pi/12}^{\theta+\pi/12}\cos\theta\,d\theta, \quad \text{or} \quad \frac{12}{\pi}\sin\frac{\pi}{12}\cos\theta.$$

Now, the value of $12\sin\frac{1}{12}\pi/\pi$ is $\cdot9886$. Hence the difference between each reduced six-monthly mean and unity must be multiplied by the factor $\frac{1}{2}\pi/\cdot9886$ or $1\cdot589$. The same remark applies to the case of taking six-half-monthly means for the semi-annual period. In like manner, in investigating the latter period by means of monthly intervals and taking three-monthly means, the corresponding augmenting factor is $1\cdot645$.

7. *Comparison of the Methods of Investigating the Semi-Annual Period.*—The method here employed for investigating the semi-annual period seems to me to possess several advantages. (1) It is less laborious to apply than Dr. KNOTT's method; (2) it avoids the interpolation of arithmetic means in the series of three-monthly and six-monthly means; and (3) it eliminates, or diminishes more completely, the effect of shorter periods, if any such should exist. The latter point requires a brief examination.

Taking Dr. KNOTT's method first, we have to evaluate the ratio

$$\frac{\dfrac{2a_n}{n\pi}\left(\sin\dfrac{n\pi}{2}-\sqrt{2}\sin\dfrac{n\pi}{4}\right)}{\dfrac{a_2\sqrt{2}}{\pi}}:\frac{a_n}{a_2}$$

for different values of n. If $n=3$, the value of this ratio is $\cdot943$; if $n=4$, it is zero; if $n=5$, it is $\cdot566$; if $n=6$, it is $\frac{1}{3}$. Hence, compared with that of the six-monthly period, the amplitude of the four-monthly period is slightly decreased, that of the period of one-fifth of a year is diminished by nearly one-half, while that of the two-monthly period is diminished by two-thirds.

In the method adopted in this paper we have to evaluate the ratio

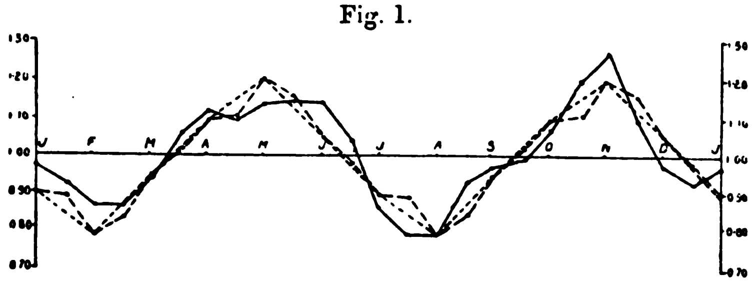
$$\frac{\dfrac{2a_n\sin\frac{1}{2}n\pi}{n\pi}}{2a_1/\pi}:\frac{a_n}{a_1}$$

for different values of n. If $n=2$, its value is zero; if $n=3$, it is $\frac{1}{3}$. Hence, the three-monthly period is eliminated, and, compared with that of the six-monthly period, the amplitude of the two-monthly period is diminished by two-thirds. Moreover, as will appear from § 10, both the four-monthly period and the period whose

length is one-fifth of a year are eliminated, provided the interval over which the seismic record extends consists of an integral number of years.

8. The curves in fig. 1 exhibit the close agreement in the results obtained by the different methods of determining the semi-annual period, the seismic record chosen being that by Professor MILNE of the earthquakes felt in Tokio during the years 1873–1881 and 1883–1890. The continuous curve is that obtained by Dr. KNOTT'S

Fig. 1.



method, every ordinate being first, however, multiplied by $\pi(\sqrt{2}-1)/2$, or ·65, so as not to alter the ratio of the amplitude to that of the annual period. The broken curve is that obtained by the method used in this paper, the earthquakes being grouped in half-months, while the dotted curve is that obtained by the same method when the earthquakes are grouped in months.

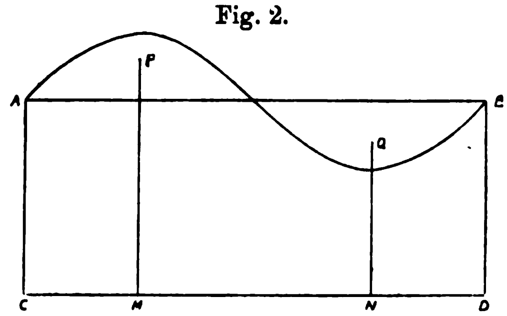
9. *Connection between the Amplitude of the Annual Period and the Winter-to-Summer Ratio in the Number of Earthquakes.*—In discussions on earthquake frequency, it is usual to estimate the ratio between the number of shocks felt during the six winter months (October to March) to the number felt during the six summer months (April to September). The ratio so obtained is, of course, only valuable when, as is frequently the case, the maximum of the annual period occurs either at the end of June or the end of December. Greater uniformity would be secured by evaluating the ratio of the number of shocks felt during the six months bisected by the maximum epoch to the number felt during the six months bisected by the minimum epoch. In the present paper, I have substituted the amplitude of the annual period for the last-named ratio, and it seems desirable to point out briefly the connection between them.

In fig. 2 let the distance AC represent the average number of earthquakes per month, and let the curve represent the annual seismic period. Let PM and QN represent the average length of the ordinates during the maximum and minimum halves of the year respectively. Then the ratio of the number of shocks felt during the maximum half to the number felt during the minimum half of the year is equal to PM : QN, *i.e.*, to the ratio of $1 + 2a/\pi$ to $1 - 2a/\pi$, where a is the amplitude of the annual period, the average number of shocks felt during each month of the year being taken as unity.

For instance, in the case of the European earthquakes of 1865–1884 as tabulated by FUCHS (see § 19), the maximum of the annual period occurs at the end of

December, the number of shocks felt during the six winter months is 3357, the number during the six summer months 2142, and the ratio of one to the other 1·57. The amplitude of the annual period is ·35, and the value of the ratio $1 + 2a/\pi : 1 - 2a/\pi$ is 1·56.

Fig. 2.



10. *Duration of the Seismic Record.*—It has been assumed in the preceding paragraphs that the curve obtained by plotting the number of earthquakes felt in each month is not affected by periods of longer duration than one year, or by periods which are not exact fractions of a year. The assumption may be tested by considering a period of $12m + n$ months, where m is either zero or a positive integer. The number of earthquakes (F_r) belonging to this period felt during the r^{th} month of each year may then be represented by

$$a \cos \alpha + a \cos (\alpha + 12\beta) + \ldots + a \cos [\alpha + (\lambda - 1) . 12\beta],$$

where $\beta = 2\pi/(12m + n)$, and λ is the number of years over which the seismic record extends. Then

$$F_r = a \cos [\alpha + (\lambda - 1) . 6\beta] \sin 6\lambda\beta/\sin 6\beta;$$

and the value of F_r is zero whatever be the value of α if $6\lambda\beta = k\pi$, where k is an integer, *i.e.*, when $\lambda = k(12m + n)/12$. Hence, F_r is zero for all values of r, and consequently our method of investigation is not affected by the period considered, provided the interval over which the seismic record extends includes an exact number of these periods.

But whatever be the number of such periods included in the seismic record, the absolute error introduced by a given uneliminated portion of a period will be constant, and, therefore, the relative error will be the less the greater the interval over which the record extends.

On another account, also, it is desirable that this interval should be as long as possible. For, owing chiefly to orogenic causes, there are often series of frequently recurring shocks, lasting for one or more months, which, if the record be a short one or imperfect, would unduly increase the numbers felt during those months. The record should therefore be an extensive one in order to eliminate the effects of occasional variability in the rate of orogenic action and to bring into special prominence those of a periodic character.

11. *Definition of the Unit Earthquake.*—The difficulty of deciding what constitutes an earthquake attends all work on seismic periodicity, and, unless some uniform and natural system is followed, our conclusions cannot possess much value. For example, every great earthquake is preceded and followed by a large number of minor or secondary shocks, which are no doubt intimately associated with the principal shock. In such a case, are we to count every shock that is recorded, however slight, or are we to regard the whole series as a single earthquake? Again, the distinction between an earthquake and earth-tremor is a purely arbitrary one. Are we to include every earth-tremor recorded by a most delicate instrument, and rank it equally with the most destructive shock; or, if not, where are we to draw the line between the two?

It must be admitted that these are serious difficulties, but I do not think they would be met, as has been proposed, by taking the intensity of the shocks into account as well as their frequency. Even supposing it possible to estimate the intensity correctly, it may be doubted whether the results obtainable in the finite time at our disposal would possess much value, at any rate from the periodicity point of view. For, whatever be the causes of seismic periodicity, it seems highly probable that they are merely auxiliary, and determine the epoch when an earthquake shall take place rather than that there shall be an earthquake at all. The intensity is probably determined almost entirely by orogenic causes, the frequency partly by the same causes, and partly by certain others which are possibly variable and periodic in their action.

I believe, then, that, in the present state of our knowledge, it is desirable to regard each shock felt and recorded as one earthquake. Moreover, an approximate uniformity in estimating the minimum intensity of an earthquake will be attained if we consider special districts of comparatively small size—countries, for example, like Italy and Switzerland, rather than continents or hemispheres.

There is still room, however, for some arbitrariness of treatment, owing to the imperfection of nearly all our seismic records. The following principles have, therefore, been adhered to throughout this paper: (1) whenever the entry in a catalogue is "several shocks about this time," or some equivalent expression, without any attempt being made to give the time of occurrence of each shock, I have always reckoned such as a single earthquake; (2) when the shocks have been considered important enough to be entered separately, the time of occurrence of each being given, every such shock has been counted, provided the interval between any two or more was not less than five minntes; and (3) shocks entered as doubtful and earthquake-sounds unaccompanied by any shocks have been omitted.

12. *Explanation of the Tables, Figures, &c.*—Table I. contains the number of earthquakes for the different districts investigated during each half-month or month. The reduced six-monthly means obtained in discussing the annual period, as described

in §§ 4 and 6 are given in Table II.; and in Table III. the reduced six half-monthly means, or three-monthly means, obtained in investigating the semi-annual period.

At the end of the section relating to each record examined, are given the maximum epoch and amplitude of each period. The epoch mentioned is the end of the month or half-month indicated, the letters *a* and *b* denoting the first and second halves of the month. The date of the maximum and the amplitude have been taken as those of the greatest mean. It would not have been difficult to have given the result more minutely, but it is doubtful whether the appearance of greater accuracy would have any value, considering the unavoidable imperfections of most seismic records.

In the same place, I have also given the date of the maximum epoch of the annual barometric period over the greater part of the district considered, excluding high-level stations. For this purpose I have made use of Dr. BUCHAN'S great work on Atmospheric Circulation.* The method of investigation is the same as that employed for the annual seismic period, except that its application is much simpler in this case.

An asterisk placed before the name of a record, either in the Tables or detailed discussion, indicates that the results obtained are probably more reliable than in other cases. The series of six-monthly and six half-monthly means calculated from these records are illustrated by the curves in figs. 5–15, the continuous line representing the annual, and the dotted line the semi-annual, period.

THE REALITY OF THE ANNUAL PERIOD.

13. It is well known that many more earthquakes are recorded as felt during the night than during the day, and that this is due partly to the stillness of the night, but more, perhaps, to the position of the body during repose being more favourable for the detection of slight tremors. Now, the maximum of the annual period occurring during winter, it may seem possible that the periodicity may be apparent only, and due to the greater number of shocks observed during the longer nights of winter. The question is one that deserves examination, and the following facts seem to me conclusive in establishing the reality of the annual period.

In the case of the earthquakes recorded at Tokio by the Gray-Milne seismograph, there can, of course, be no doubt. But this is the only case treated in this paper in which the shocks are registered entirely by instrumental means.

The hours of rest may be taken roughly at between 10 P.M. and 8 A.M., and we may therefore divide the day into two parts, reckoning day-time from 9 A.M. to 9 P.M., and night-time from 9 P.M. to 9 A.M. Using FUCHS' valuable 'Statistik der Erdbeben,' I have counted the number of shocks, whose time of occurrence is recorded, in Austria,

* "Report on Atmospheric Circulation, based on the Observations made on board H.M.S. Challenger during the years 1873–1876, and other Meteorological Observations." 'Report of the Scientific Results of the Voyage of H.M.S. Challenger, &c.; Physics and Chemistry,' vol. 2, 1889, pp. 1–263.

Hungary, and Switzerland during the years 1865–1884, and in Italy during the years 1865–1883. The total number is 2253. In the six summer months (April to September) the number of shocks felt during the night was 545, and during the day 358. In the six winter months (October to March) the number felt during the night was 821, and during the day 529. Thus, the ratio of the number of shocks observed during the night to that observed during the day was 1·52 in summer and 1·55 in winter. These ratios agree so closely that we may feel confident as to the reality of any marked annual period observable in these countries.

Again, the annual period is well marked in several tropical districts where the length of the night is nearly constant throughout the year. And, also, as will presently appear, there is an annual period, though of slight amplitude, in earthquakes which produce damage to buildings, and shocks of intensity so great could not possibly escape observation at any time of the night or day.

SEISMIC PERIODICITY IN RELATION TO INTENSITY.

14. If the causes of seismic periodicity are in the main auxiliary, as has been suggested above, it seems possible that the periodicity might be more marked in the case of very slight, than of very severe, earthquakes. An attempt is therefore made in the present section to classify earthquakes according to their intensity, so far as it is possible to do so with the incomplete materials at our disposal. For this purpose I have in the first place used MALLET's well-known catalogue,* and have selected from the shocks recorded by him: (1) those which may be regarded as slight, and (2) those which are strong enough to damage buildings; the latter class corresponding to intensities 8 to 10 of the Rossi-Forel scale, and the former, probably, to intensities 3 and 4. Both classes contain earthquakes felt in the northern hemisphere only.

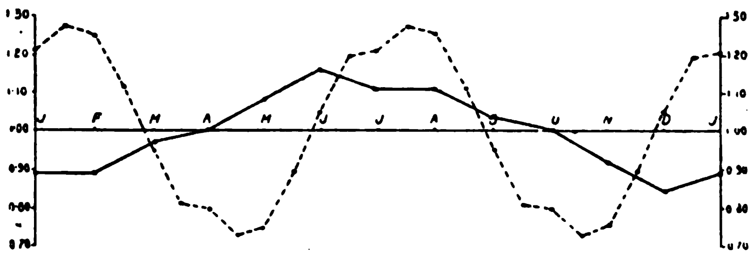
Slight Earthquakes.—The shocks included under this heading are those which, from MALLET's description,† can have been hardly more than perceptible even at the places where the intensity was greatest. When two or more such shocks are felt within the same area on the same day, these have been omitted, for they may be regarded as equivalent to a single shock of greater intensity. And, for the same reason, I have excluded isolated slight shocks which are members of a long and continuous series of earthquakes of variable intensity. This has been done in four

* "Catalogue of recorded Earthquakes," 'Brit. Assoc. Rep.,' 1852, pp. 1–176; 1853, pp. 117–212; 1854, pp. 1–326.

† The following are the terms employed by MALLET which I have taken to characterize a slight shock:—A tremor, a trembling, a slight trembling, a slight tremor, a slight tremulous shock, a trembling shock, a very feeble shock, a feeble vibration, a very slight shock, a slight shock, a slight vibration, a slight earthquake, a scarcely perceptible shock, a slight vibratory shock, rather slight, of trifling importance, a feeble shock, a trifling shock, a little shock, a slight undulatory motion, a very slight subterranean commotion, a slight undulatory shock, a slight oscillating motion.

cases, namely, the series felt at Tiflis in Georgia in 1804, at Pignerol and other places in Piedmont during 1808 and following years, at Lunröe in Norway, beginning in 1819, and at Pesaro in Italy during the year 1826. The period investigated is that embraced by the third part of MALLET's catalogue—the years 1785–1842 inclusive.

Fig. 3.



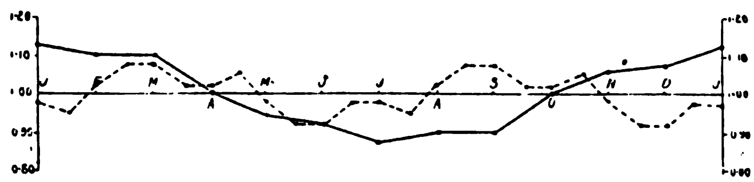
Slight earthquakes.

It seemed desirable to limit it thus closely in order to avoid any considerable variability in the estimation of a "slight" shock. The total number of such shocks is 187. The curves of the annual and semi-annual periods are shown in fig. 3.

Period.	Maximum.	Amplitude.
Annual.	June, *b*	·16
Semi-annual	January, *b* July, *b*	·27

Destructive Earthquakes.—Only those earthquakes have been counted in which it is expressly stated that some damage was done to buildings. The whole of the Christian era is included, but the first earthquake on which the month and day are

Fig. 4.



Destructive earthquakes.

definitely stated occurred in the year 528, and in several succeeding centuries the year is frequently the only date given. The total number of destructive earthquakes recorded by MALLET is 641. The curves of the annual and semi-annual period are shown in fig. 4.

Period.	Maximum.	Amplitude.
Annual	January, *b*	·13
Semi-annual	February, *b*—March, *a* · August, *b*—September, *a*	·08

It follows from this examination, imperfect as it is, (1) that in slight earthquakes both periods are more marked than in destructive ones, but that this is especially the case with the semi-annual period, the amplitude of the annual period being increased 1·2 times, and that of the semi-annual period 3·4 times; and (2) that the maximum epochs of the annual period are almost reversed.

15. *Japanese Earthquakes of* 1885–1889.—The organization of earthquake statistics in Japan is under the direction of the Imperial Meteorological Bureau. Reports are issued yearly, and abridged translations of these for the years 1885–1889, have been published by Professor S. SEKIYA and Professor J. MILNE (see § 51). Professor MILNE has classified the earthquakes in monthly groups according to the areas disturbed by them. The results are given below, but it should be remembered that the duration of the record is short; also that the areas given are land areas only, and many Japanese earthquakes originate beneath the sea.

(1.) Earthquakes disturbing an area less than 100 square ri (1 square ri = 5·9 square miles). Number of earthquakes, 2256.

Period.	Maximum.	Amplitude.
Annual	September, *b*—October, *b*	·14
Semi-annual	March, *a* September, *a*	·12

(2.) Earthquakes disturbing an area less than 1000 square ri and greater than 100 square ri. Number of earthquakes, 565.

Period.	Maximum.	Amplitude.
Annual	February, *b*—March, *b*	·17
Semi-annual	June, *a* December, *a*	·16

(3.) Earthquakes disturbing an area greater than 1000 square ri. Number of

Period.	Maximum.	Amplitude.
Annual	March, *b*	·17
Semi-annual	{ March, *a* September, *a* }	·12

Thus, (1) the amplitudes of both periods in all three classes are nearly the same, though somewhat less for the slight shocks than the others; and (2) in the case of the annual period, the maximum epoch for the slight shocks agrees nearly with the minimum epoch for the more severe ones.

16. In nearly every case examined below, in which we have two or more records for the same area, it will be seen that the amplitude increases with the number of registered shocks per annum. Now, two records can only differ in this respect by the omission or inclusion of slight shocks, for severe ones are almost certain to find a place in every list. Thus, in these cases, the slighter the earthquakes the greater is the amplitude of each period.

This is especially evident when, with the same catalogue, we use different definitions of the unit earthquake. This has been done in three cases, namely, Zante (§§ 45, 46), California, &c., (§§ 59, 60), and New Zealand (§§ 76, 77).

Again, for Zante, the somewhat scanty list compiled from the catalogues of SCHMIDT and FUCHS (§ 47) gives the maximum of the annual period in December, and the amplitude ·29; the much fuller catalogue of BARBIANI (§§ 45, 46) gives the maximum in August, and the amplitude ·10, or, using BARBIANI's definition of the unit earthquake, the maximum in August, and the amplitude ·29. Thus, the effect of the first inclusion of slight shocks is to reverse approximately the maximum and minimum epochs, but to reduce the amplitude; the effect of including a larger number of still slighter shocks is to maintain the reversal of epoch and to again increase the amplitude.

17. *Summary of Results.*—(1) There appear to be two distinct classes of slight shocks, one having the maximum of its annual period in winter, the other in summer. Of the two classes, the former probably contains the stronger shocks, for their effect is evident in the results obtained from the less incomplete of two imperfect catalogues; while the effect of the latter is only visible in the results obtained from the fullest records, for example, those of the Imperial Meteorological Bureau for Japan, and of M. BARBIANI for Zante, or from the list drawn up from MALLET's catalogue in which only very slight shocks are included. (2) In both classes of slight shocks the annual period is more marked than for strong shocks, for the effect of including the first class of slight shocks is to keep the winter maximum epoch unaltered and to increase the amplitude; that of including some only of the second class is to interchange the maximum and minimum epochs approximately, the

amplitude of the period being diminished; while the effect of including a large number of slight shocks of the second class is to keep the epochs interchanged and to increase the amplitude. (3) With regard to the semi-annual period, the results, as a rule, show that strong shocks and slight shocks have the same maximum epochs, but that the amplitude for the latter is somewhat greater than for the former.

SEISMIC PERIODICITY IN THE NORTHERN HEMISPHERE.

Northern Hemisphere.

18. R. MALLET, "Catalogue of Recorded Earthquakes from 1606 B.C. to A.D. 1850." 'Brit. Assoc. Rep.,' 1852, pp. 1–176; 1853, pp. 118–212; 1854, pp. 1–326; 1858, pp. 46 and 57.

Duration of record, A.D. 223–1850. Number of earthquakes, 5879.

MALLET'S great catalogue includes several earthquakes which occurred before the Christian era, but the first in which the month is stated was felt in the year A.D. 223. It closes with the end of the year 1842, though he originally intended to bring it down to the end of 1850. M. PERREY'S catalogues, which rendered the continuation unnecessary, were, however, used by MALLET in his final discussion in his "Fourth Report." It was found necessary to make some convention with regard to the long-continued series of slight shocks or tremors felt at several places (Pignerol, Comrie, &c.), and in these cases "the slight shocks recorded for each month of the disturbed period are grouped as forming one earthquake at the locality." It will be seen from Table II. that the six-monthly means for November, December and January are the same. I have taken the intermediate month as the date of the annual maximum.

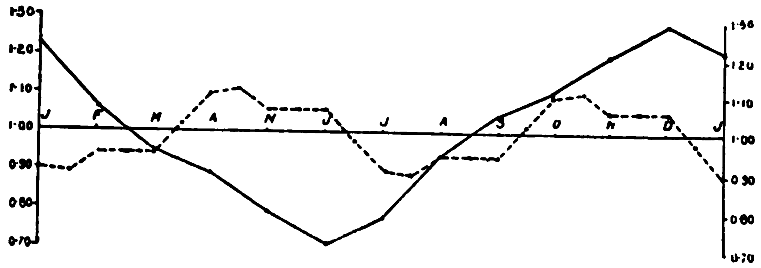
Period.	Maximum.	Amplitude.
Annual	December, *b*	·11
Semi-annual	February, *a* August, *a*	·07

19. *C. W. C. FUCHS, 'Statistik der Erdbeben,' pp. 13–286, 315–321, 357–408.

Duration of record, 1865–1884. Number of earthquakes, 8133 (fig. 5).

This number includes all the earthquakes recorded by FUCHS as occurring in the northern hemisphere, with the exception of those felt in the northern part of the Malay Archipelago. I have also omitted a few shocks in places which I am unable to identify, but the number of these is so small that it cannot possibly affect the result. The same remark applies to the discussion for FUCHS' catalogues for the

Fig. 5.



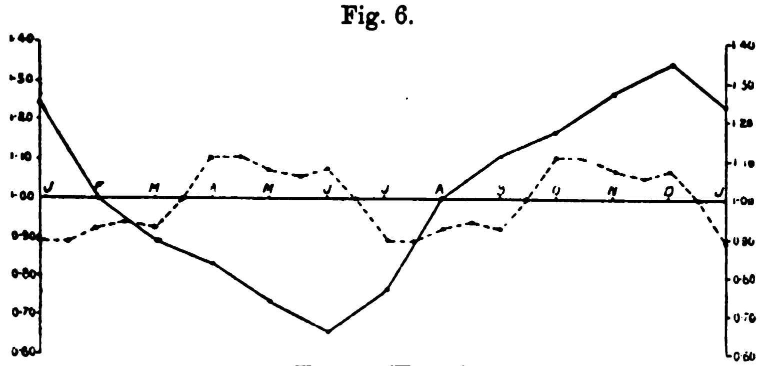
Northern hemisphere (FUCHS).

Period.	Maximum.	Amplitude.
Annual	December, *b*	·29
Semi-annual	{ April, *b* / October, *b* }	·11
Annual barometric . . .	November, *b*, or December, *b*	

Europe.

20. *C. W. C. FUCHS, 'Statistik der Erdbeben,' pp. 13–254 (fig. 6). Duration of record, 1865–1884. Number of earthquakes, 5499.

Fig. 6.



Europe (FUCHS).

Period.	Maximum.	Amplitude.
Annual	December, *b*	·35
Semi-annual	{ April, *a*—April, *b* / October, *a*—October, *b* }	·11
Annual barometric . . .	November, *b*	

21. A. PERREY, 'Brit. Assoc. Rep.,' 1858, p. 28.

Duration of record, 306–1843. Number of earthquakes, 1961.

This is the table used in Dr. KNOTT's Memoir on "Earthquake Frequency," referred to at the beginning of this paper. The district includes also the adjacent parts of Asia and Africa.

Period.	Maximum.	Amplitude.
Annual	December, *b*	·22
Semi-annual	January, *a* July, *a*	·12

Scandinavia and Iceland.

22. A. PERREY, 'Brit. Assoc. Rep.,' 1858, p. 3.

Duration of record, 12th to 19th centuries. Number of earthquakes, 214.

Period.	Maximum.	Amplitude.
Annual	December, *b*	·30
Semi-annual	February, *a* August, *a*	·22

The maximum epoch of the annual barometric period occurs in June, *b*, in the greater part of Norway, and in March, *b*, in the south of Norway, and nearly all over Sweden.

Great Britain.

23. A. PERREY, 'Brit. Assoc. Rep.,' 1858, p. 5.

Duration of record, 11th to 19th centuries. Number of earthquakes, 217.

The results deduced from this table are of less value than those given below, especially those obtained from Mr. ROPER's list. PERREY's district is more extensive than the others, being the "British Islands and Northern Isles."

Period.	Maximum.	Amplitude.
Annual	October, *b*	·32
Semi-annual	April, *a* October, *a*	·08

24. D. Milne, "Notices of Earthquake-shocks felt in Great Britain, and especially in Scotland," &c. 'Edinburgh New Phil. Journ.,' 1841, vol. 31, pp. 95-122.

Duration of record, 1608–1838. Number of earthquakes, 205.

The figures for this district in Table I. differ somewhat from those given by Mr. Milne on p. 289 of his paper. Some of the shocks counted by him are omitted on account of the rules laid down in § 11, others, because they were felt in Jersey and Guernsey.

Period.	Maximum.	Amplitude.
Annual	November, *b*	·49
Semi-annual	March, *a* September, *a*	·16

25. W. Roper, "A List of the more Remarkable Earthquakes in Great Britain and Ireland during the Christian Era," 1889. (Published by T. Bell, "Observer" Office, Lancaster.)

Duration of record, 1739–1888. Number of earthquakes, 297.

This list is compiled from Perrey's and Mallet's catalogues and various other sources. Before the year 1739 the exact day of occurrence is often imperfectly given. Slight shocks, like those felt at Comrie, are omitted from the list, and this deprives it of much of its value for statistical purposes. I have excluded all earthquakes whose origin probably lay outside the area of Great Britain.

Period.	Maximum.	Amplitude.
Annual	January, *b*	·29
Semi-annual.	March, *a* September, *a*	·11

The maximum epoch of the annual barometric period occurs in June, *b*, in the north of Scotland; May, *b*, in the south of Scotland; and March, *b*, over most of England.

France, &c.

26. C. W. C. Fuchs, 'Statistik der Erdbeben,' pp. 117-127.

Duration of record, 1865–1884. Number of earthquakes, 193.

The number of earthquakes is small, and, during November 26–29, 1873, there was a series of twenty-four shocks at Bagnères de Bigorre. On these accounts the results obtained are hardly satisfactory.

Period.	Maximum.	Amplitude.
Annual	December, *b*	·41
Semi-annual	None	

27. A. PERREY, 'Brit. Assoc. Rep.,' 1858, p. 11.

Duration of record, 5th to 19th centuries. Number of earthquakes, 656.

PERREY's region includes France, Belgium, and Holland, the limits of which, MALLET remarks, are fixed somewhat arbitrarily.

Period.	Maximum.	Amplitude.
Annual	January, *b*	·33
Semi-annual	January, *a* July, *a*	·10

The maximum epoch of the annual barometric period generally occurs in November, *b*, in France, and in March, *b*, in Belgium and Holland. Over a large part of France, however, the six-monthly means are irregular.

Spain and Portugal.

28. A. PERREY, 'Brit. Assoc. Rep.,' 1858, p. 8.

Duration of record, 12th to 19th centuries. Number of earthquakes, 201.

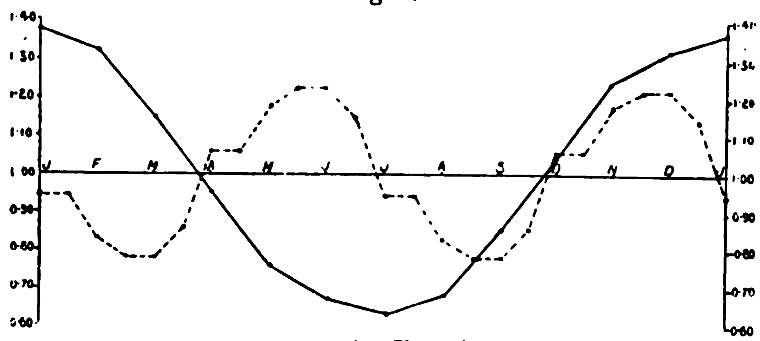
Period.	Maximum.	Amplitude.
Annual	December, *b*	·21
Semi-annual	Probably none	
Annual barometric . . .	November, *b*	

Austria.

29. *C. W. C. FUCHS, 'Statistik der Erdbeben,' pp. 13–37.

Duration of record, 1865–1884. Number of earthquakes, 461 (fig. 7).

Fig. 7.



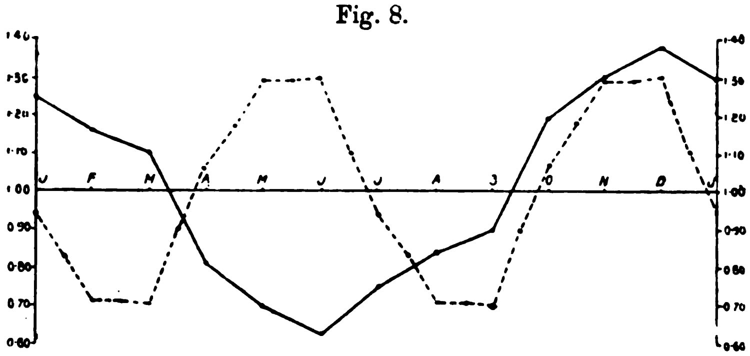
Austria (Fuchs).

Period.	Maximum.	Amplitude.
Annual.	January, *b*	·37
Semi-annual	May, *b*—June, *a* November, *b*—December, *a*	·22
Annual barometric . . .	November, *b*	

Hungary, Croatia, and Transylvania.

C. W. C. Fuchs, 'Statistik der Erdbeben,' pp. 47–65.
tion of record, 1865–1884. Number of earthquakes, 384 (fig. 8).

Fig. 8.



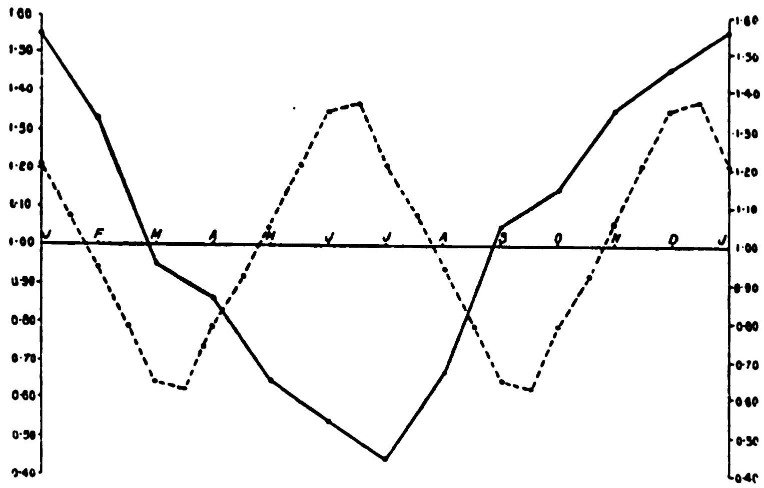
Hungary, Croatia, and Transylvania (Fuchs).

Period.	Maximum.	Amplitude.
Annual.	December, *b*	·31
Semi-annual	June, *a* December, *a*	·30
Annual barometric	November, *b*	

Switzerland and the Tyrol.

31. *C. W. C. FUCHS, 'Statistik der Erdbeben,' pp. 37–44, 99–117.
Duration of record: Switzerland, 1865–1884; Tyrol, 1865–1882. Number of earthquakes: Switzerland, 411; Tyrol, 113; total, 524 (fig. 9).

Fig. 9.



Switzerland and the Tyrol (FUCHS).

Period.	Maximum.	Amplitude.
Annual	January, *b*	·56
Semi-annual	June, *b* December, *b*	·37
Annual barometric . . .	November, *b*	

Basin of the Rhone.

32. A. PERREY, 'Brit. Assoc. Rep.,' 1848, p. 12.
Duration of record, 16th to 19th centuries. Number of earthquakes, 184.

Period.	Maximum.	Amplitude.
Annual	November, *b*	·46
Semi-annual	January, *a*—February, *a* July, *a*—August, *a*	·13

Basin of the Rhine and Switzerland.

33. A. PERREY, 'Brit. Assoc. Rep.,' 1858, p. 13.
Duration of record, 9th to 19th centuries. Number of earthquakes, 529.

Period.	Maximum.	Amplitude.
Annual	January, *b*	·38
Semi-annual	June, *a* December, *a*	·15

Basin of the Danube.

34. A. PERREY, 'Brit. Assoc. Rep.,' 1858, p. 14.
Duration of record, 5th to 19th centuries. Number of earthquakes, 268.

Period.	Maximum.	Amplitude.
Annual.	November, *b*	·14
Semi-annual	January, *a* July, *a*	·30

Italy.

35. A. PERREY, 'Brit. Assoc. Rep.,' 1858, p. 16.
Duration of record, 5th to 19th centuries. Number of earthquakes, 984.
PERREY's district includes the whole of Italy, Sicily, Malta, and Sardinia, as well as the part of the Alpine region not included in Savoy or the basins of the Rhine, Rhone, and Danube.

Period.	Maximum.	Amplitude.
Annual.	March, *b*	·19
emi-annual	March, *a* September, *a*	·08

36. C. W. C. FUCHS, 'Statistik der Erdbeben,' pp. 144–225.
Duration of record, 1865–1883. Number of earthquakes, 2350.
FUCHS classifies the Italian earthquakes under three headings: Italy without the district round Vesuvius, the district round Vesuvius, and Sicily. The results for the

three separate regions are given below. The region here considered includes all three. The value of the result is affected by the large number of earthquakes felt in Sicily during March, 1883.

Period.	Maximum.	Amplitude.
Annual.	September, *b* and December, *b*	·14
Semi-annual.	{ April, *b* / October, *b* }	·14
Annual barometric. . .	November, *b*	

37. *Italy, excluding Sicily and the district round Vesuvius.*—C. W. C. Fuchs, 'Statistik der Erdbeben,' pp. 144–197.

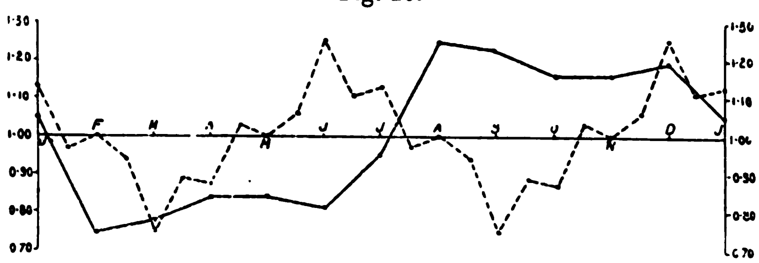
Duration of record, 1865–1883. Number of earthquakes, 1513.

Period.	Maximum.	Amplitude.
Annual.	September, *b* and November, *b*	·21
Semi-annual	{ April, *a*—April, *b* / October, *a*—October, *b* }	·17

38. * *District round Vesuvius.*—C. W. C. Fuchs, 'Statistik der Erdbeben,' pp. 198–213.

Duration of record, 1865–1883. Number of earthquakes, 513.

Fig. 10.



District round Vesuvius (Fuchs).

Period.	Maximum.	Amplitude.
Annual	August, *b*	·25
Semi-annual.	{ June, *a* / December, *a* }	·25
Annual barometric (Naples)	November, *b*	

39. *Sicily.*—C. W. C. FUCHS, 'Statistik der Erdbeben,' pp. 213–224.

Duration of record, 1865–1883. Number of earthquakes, 324.

The results, as pointed out above (§ 36), are not of great value, owing to the large number of shocks felt during March, 1883.*

Period.	Maximum.	Amplitude.
Annual	May, *b*	·67
Semi-annual	February, *b* August, *b*	·46
Annual barometric	November, *b*	

40. It may be interesting to compare with these results the observations made by P. T. BERTELLI on the relative microseismic intensity at Florence. These are summarized for the interval December, 1872, to November, 1887, in his paper, "Delle variazioni dei valori d'Intensità Tromometrica relativa osservata nel Collegio alla Querce di Firenze dell' anno meteorico 1872–73 al 1886–87." Observations were made with two tromometers which are termed the "old tromometer" and the "normal tromometer"; with the first for the whole period of 15 years, and with the second for the last 11 years.

(1.) Old tromometer, December, 1872–November, 1887. 61,732 observations.

Period.	Maximum.	Amplitude.
Annual	December, *b*	·49
Semi-annual	May, *a*—June, *a* November, *a*—December, *a*	·08

* If we omit this year we get the following results, which agree more closely with those obtained from the Vesuvian district (the number of earthquakes being 242).

Period.	Maximum.	Amplitude.
Annual	July, *b*	·50
Semi-annual	June, *b* December, *b*	·19

(2.) Old tromometer, December, 1876–November, 1887. 38,546 observations.

Period.	Maximum.	Amplitude.
Annual	December, *b*	·46
Semi-annual	May, *a* November, *a*	·04

(3.) Normal tromometer, December, 1876–November, 1887. 38,546 observations.

Period.	Maximum.	Amplitude.
Annual	December, *b*	·49
Semi-annual	May, *a* November, *a*	·03

41. The results obtained above for Italy are somewhat discordant. We may conclude, however: (1) that the maximum of the annual seismic period occurs some time during the last three months of the year, and the maxima of the semi-annual period in April and October; the amplitudes of both periods being approximately equal; (2) that the maximum of the annual period in the two volcanic districts occurs during the summer months; and (3) that there is a marked annual microseismic period, with its maximum occurring at the end of December, the semi-annual microseismic period being comparatively very slight.

South-east of Europe, &c.

42. A. PERREY, 'Brit. Assoc. Rep.,' 1858, p. 18.

Duration of record, 4th to 19th centuries. Number of earthquakes, 423.

PERREY's district includes the whole of the Balkan peninsula, Syria, the Ægean Islands, and the Levant. The seismic record is admittedly incomplete.

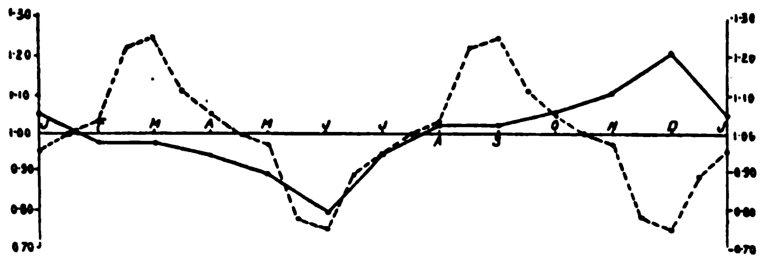
Period.	Maximum.	Amplitude.
Annual	Irregular	
Semi-annual	February, *a* August, *a*	·08

43. *J. F. J. Schmidt, 'Studien über Erdbeben' (Leipzig, 1879), pp. 183–355.

Duration of record, 1859–1877. Number of earthquakes, 3470 (fig. 11).

This district is also a wide one, including the Balkan peninsula and adjacent islands, and parts of Turkey in Asia.

Fig. 11.



South-east Europe, &c. (Schmidt).

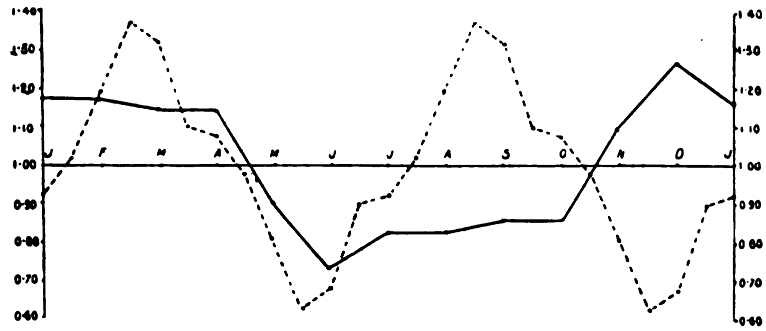
Period.	Maximum.	Amplitude.
Annual	December, *b*	·21
Semi-annual	{ March, *a* / September, *a* }	·25
Annual barometric . . .	November, *b* and December, *b*	

44. **Balkan Peninsula and adjacent Islands.*—C. W. C. Fuchs, 'Statistik der Erdbeben,' pp. 44–47, 225–251.

Duration of record, 1865–1884. Number of earthquakes, 624 (fig. 12).

This region contains Dalmatia as well as that included by Fuchs under the above heading.

Fig. 12.



Balkan peninsula, &c. (Fuchs).

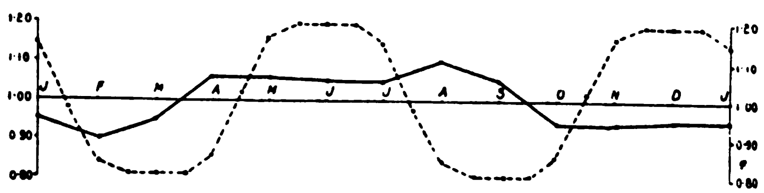
Period.	Maximum.	Amplitude.
Annual	December, *b*	·27
Semi-annual	February, *b* August, *b*	·37
Annual barometric . . .	November, *b*	

45. **Zante.*—D. G. and B. A. Barbiani, "Mémoire sur les tremblements de terre dans l'île de Zante;" 'Mém. de l'Académie de Dijon,' vol. 11, 1863, pp. 1–112.

Duration of record, 1825–1863. Number of earthquakes, 1326 (fig. 13).

These figures show that, on an average, at least 34 earthquakes were felt every year. This number is, however, too small, for the number of shocks following the disastrous earthquake of October 30, 1840, was so great that M. Barbiani found it impossible to record them all. According to the report issued by the Lord High Commissioner, Sir Howard Douglas, 95 shocks, some very severe, were felt between October 30 and November 4. M. Barbiani gives an estimate of the total number of shocks (p. 103), and in the next paragraph I have discussed the figures given by him.

Fig. 13.



Zante (Barbiani).

Period.	Maximum.	Amplitude.
Annual	August, *b*	·10
Semi-annual	June, *a* December, *a*	·19

46. D. G. Barbiani, p. 103.

Number of earthquakes, 1663.

M. Barbiani's estimate of the monthly number of shocks differs from the preceding, owing to his including several slight shocks which he counted, without giving the time of occurrence of each, as well as to his estimate of the number of shocks in the early part of November, 1840.

Period.	Maximum.	Amplitude.
Annual.	August, *b*	·29
Semi-annual	May, *a* November, *a*	·35

Thus, the effect of including these slighter shocks is to increase the amplitude of both periods, and to place the maximum epoch of the semi-annual period a month earlier.

47. *Zante.*—SCHMIDT and FUCHS.

Duration of record, 1859–1878. Number of earthquakes, 246.

The list on which this discussion is founded is compiled from those given by SCHMIDT and FUCHS for the south-east of Europe. The former extending from 1859 to 1878, the latter from 1865 to 1884, though not recording any shocks later than 1874. For the years 1859 to 1863, SCHMIDT's records, with only seven exceptions, are all taken from BARBIANI's catalogue. For the remainder of the time, SCHMIDT and FUCHS do not seem to have made use of the same authorities, for their dates agree in only a comparatively small number of cases.

Period.	Maximum.	Amplitude.
Annual.	December, *b*	·29
Semi-annual	March, *a* September, *a*	·33

Now, the average number of earthquakes felt in Zante every year is 34·8 or 43·8 according to BARBIANI, and 8·2 according to the list compiled from SCHMIDT's and FUCHS' catalogues. M. BARBIANI's catalogue may perhaps relate to a more than usually disturbed interval, but it was compiled by a resident in the island, and therefore probably includes a much greater number of slight shocks than the other list. This may account for the difference in the maximum epoch of the annual period

Algeria.

48. C. W. C. Fuchs, 'Statistik der Erdbeben,' pp. 317–321.
Duration of record, 1865–1883. Number of earthquakes, 135.

Period.	Maximum.	Amplitude.
Annual	December, *b*	·67
Semi-annual	June, *a*—June, *b* December, *a*—December, *b*	·30
Annual barometric . . .	November, *b*, and December, *b*	

Asia.

49. C. W. C. Fuchs, 'Statistik der Erdbeben,' pp. 254–276.
Duration of record, 1865–1884. Number of earthquakes, 458.

The region considered includes Caucasia, which is treated separately (§ 50), and India, but excludes Japan, Formosa, and the Malay Archipelago. The record is probably incomplete.

Period.	Maximum.	Amplitude.
Annual	February, *b*	·33
Semi-annual	February, *a* August, *a*	·14
Annual barometric . .	December, *b*	

Caucasia.

50. C. W. C. Fuchs, 'Statistik der Erdbeben,' pp. 257–263.
Duration of record, 1865–1884. Number of earthquakes, 152.

Period.	Maximum.	Amplitude.
Annual	January, *b*	·56
Semi-annual	February, *a* August, *a*	·38
Annual barometric . .	December, *b*	

Japan.

51. 'Trans. of Seismol. Soc. of Japan,' vol. 10, 1887, p. 61; vol. 13, Part 1, 1889, p. 93; vol. 15, 1890, p. 101; vol. 16, 1892, pp. 56 and 83.

Duration of record, 1885–1889. Number of earthquakes, 2997.

This record has already been discussed in § 17, with reference to seismic intensity. The early epoch of the annual period is due to the very large number of shocks disturbing an area less than 100 square ri.

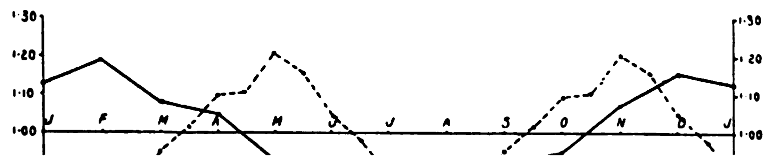
Period.	Maximum.	Amplitude.
Annual	October, *b*	·08
Semi-annual	March, *a* September, *a*	·07
Annual barometric . .	December, *b*	

52. **Tokio*.—Professor J. MILNE, 'Trans. of Seismol. Soc. of Japan,' vol. 2, 1880, pp. 4–14, 39; vol. 6, 1883, pp. 32–35; vol. 8, 1885, pp. 100–108; vol. 10, 1887, pp. 97–99; vol. 15, 1890, pp. 127–134. Also (for the earthquakes recorded by the Gray-Milne seismograph) 'Brit. Assoc. Rep.,' 1886, pp. 414–415; 1887, pp. 212–213; 1888, pp. 435–437; 1889, pp. 295–296; 1890, pp. 160–162; 1891, pp. 123–124; 1892, pp. 93–95.

Duration of record, 1876–1881 and 1883–1891. Number of earthquakes, 1104 (fig. 14).

Professor MILNE's record of earthquakes felt in Tokio, begins in September, 1872. From the end of 1875 until the present time, the earthquakes were all registered by instrumental means. PALMIERI's seismograph was used until April, 1885, and the Gray-Milne seismograph after that date. At the end of the year 1882, observations were suspended during the removal of the instrument; this year is accordingly omitted.

Fig. 14.



Period.	Maximum.	Amplitude.
Annual	February, *b*	·19
Semi-annual	May, *a* November, *a*	·21
Annual barometric (Tokio) .	December, *b*	

Omitting the year 1885, during which the change of seismographs was made, we have the following results, differing but slightly from the preceding. (Number of earthquakes, 1039.)

Period.	Maximum.	Amplitude.
Annual	February, *b*	·19
Semi-annual	May, *a* November, *a*	·22

53. *Tokio.*—Professor J. MILNE, 'Trans. of Seismol. Soc. of Japan,' vol. 2, 1880, pp. 7–14, 39.

Duration of record, 1878–1881. Number of earthquakes, 246.

The results for this shorter interval are given for comparison with those from the next district.

Period.	Maximum.	Amplitude.
Annual	December, *b*	·46
Semi-annual	January, *b* July, *b*	·19

54. *Yokohama.*—T. H. STREETS, M.D. (U.S. Navy), "A Four Years' Record of Earthquakes in Japan, studied in their Relation to the Weather and Seasons": 'Amer. Journ. of Science', 3rd ser., vol. 25, 1883, pp. 361–367.

Duration of record, 1878–1881. Number of earthquakes, 130.

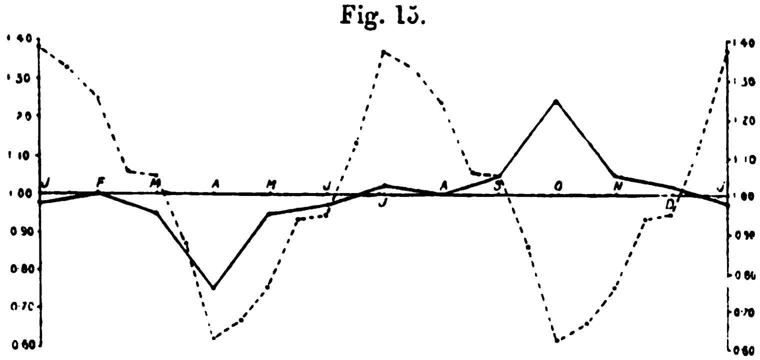
Dr. STREETS' list is compiled from the weather statistics kept at the United States Naval Hospital at Yokohama, a station for taking international meteorological observations. It "includes every shock that could be appreciated without the aid of a seismometer." The results are interesting as showing the fairly close agreement in lists kept at places separated by a few miles, one with, and the other without, the aid of a seismograph ; but they possess little value otherwise

Period.	Maximum.	Amplitude.
Annual	December, *b* and March, *b*	·41
Semi-annual	{ January, *b* July, *b* }	·29

India.

55. *T. OLDHAM, "A Catalogue of Indian Earthquakes from the Earliest Time to the End of A.D. 1869"; 'India Geol. Survey Mem.,' vol. 19, part 3, pp. 1–48.
Duration of record, 1803–1869. Number of earthquakes, 320 (fig. 15.)

Fig. 15.



India (OLDHAM).

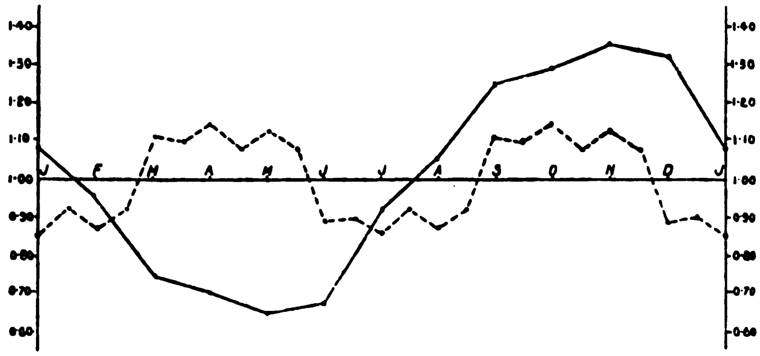
Period.	Maximum.	Amplitude.
Annual	October, *b*	·25
Semi-annual	{ January, *a* July, *a* }	·38

North America.

56. *C. W. C. FUCHS, 'Statistik der Erdbeben,' pp. 377–401.
Duration of record, 1865–1884. Number of earthquakes, 552 (fig. 16).
This district includes the whole of the continent north of Mexico.

Period.	Maximum.	Amplitude.
Annual	November, *b*	·35
Semi-annual	{ April, *a* October, *a* }	·14
Annual barometric . .	November, *b* and December, *b*	

Fig. 16.



North America (Fuchs).

United States and Canada.

57. A. Perrey, 'Brit. Assoc. Rep.,' 1858, p. 23.

Duration of record, 17th to 19th centuries. Number of earthquakes, 134.

Period.	Maximum.	Amplitude.
Annual	December, *b*	·46
Semi-annual	January, *a* July, *a*	·15
Annual barometric . . .	November, *b* and December, *b*	

New England.

58. W. T. Brigham, "Volcanic Manifestations in New England, being an Enumeration of the Principal Earthquakes from 1638 to 1869"; 'Boston Soc. Nat. Hist. Mem.,' vol. 2, 1873, pp. 1–28.

Duration of record, 1638–1869. Number of earthquakes, 212.

Period.	Maximum.	Amplitude.
Annual	December, *b*	·51
Semi-annual	June, *b* December, *b*	·25
Annual barometric . . .	November, *b*	

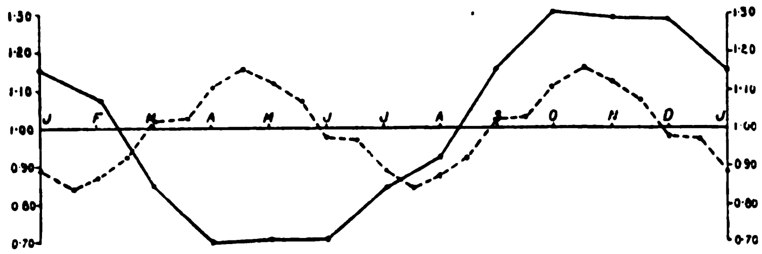
California, &c.

59. *E. S. HOLDEN, "List of Recorded Earthquakes in California, Lower California, Oregon, and Washington Territory" (Sacramento, 1887).

Duration of record, 1850–1886. Number of earthquakes, 949 (fig. 17).

The six-monthly means for October, November, and December being very nearly equal, it is possible that the epoch of the maximum of the annual period may be placed too early.

Fig. 17.



California, &c. (HOLDEN).

Period.	Maximum.	Amplitude.
Annual	October, *b*	·30
Semi-annual	April, *b* October, *a*	·16
Annual barometric . . .	December, *b* and January, *b*	

60. In Table A. of his memoir (p. 11) Professor HOLDEN has given the number of earthquakes for each year grouped in monthly intervals. Using these figures, we have the following results (the number of earthquakes being 768) :—

Period.	Maximum.	Amplitude.
Annual	October, *b*	·19
Semi-annual	April, *a* October, *a*	·16

Thus, while the maximum epochs are practically the same, as also the amplitude of the semi-annual period, the amplitude of the annual period increases with the number of earthquakes, that is, by including a greater number of slight shocks.

61. *San Francisco.*—E. S. HOLDEN, p. 13, Table B.
Duration of record, 1850–1886. Number of earthquakes, 254.

Period.	Maximum.	Amplitude.
Annual	December, *b*	·41
Semi-annual	April, *a* October, *a*	·21
Annual barometric (San Francisco)	January, *b*	

62. *San José and Santa Clara.*—E. S. HOLDEN, p. 15, Table C.
Duration of record, 1850–1886. Number of earthquakes, 54.

Professor HOLDEN remarks that the record for these two places is very incomplete; he thinks that probably, if the record had been well kept, the number would have been as great as at San Francisco. As it is, it is too small to yield reliable results.

Period.	Maximum.	Amplitude.
Annual	December, *b*	·56
Semi-annual	March, *a* September, *a*	·33

Mexico.

63. C. W. C. FUCHS, 'Statistik der Erdbeben,' pp. 372–376.
Duration of record, 1865–1882 Number of earthquakes, 86.
The annual period, if one exists, is very irregular.

Period.	Maximum.	Amplitude.
Annual	December, *b*	·43
Semi-annual	April, *a* October, *a*	·79

The maximum of the annual barometric period occurs in January at places near the sea-level, and in September and October on the high ground which occupies so

Central America.

64. C. W. C. FUCHS, 'Statistik der Erdbeben,' pp. 357-363.
Duration of record, 1865-1884. Number of earthquakes, 190.

Period.	Maximum.	Amplitude.
Annual	April, *b*	·32
Semi-annual	April, *a* October, *a*	·25
Annual barometric . . .	January, *b*—April, *b*	

West Indies.

65. C. W. C. FUCHS, 'Statistik der Erdbeben,' pp. 364-371.
Duration of record, 1865-1883. Number of earthquakes, 205.

In November, 1867, a large number of earthquakes were felt at St. Thomas, more than four hundred between the 19th and 28th insts. Except in the few cases where the exact times are given, the shocks of each day are counted as a single earthquake.

Period.	Maximum.	Amplitude.
Annual	October, *b*	·59
Semi-annual	June, *b* December, *b*	·59
Annual barometric . . .	January, *b*—April, *b*	

66. A. PERREY, 'Brit. Assoc. Rep.,' 1858, pp. 24, 25.
Duration of record, 16th to 19th centuries. Number of earthquakes, 221.

MALLET remarks that PERREY was obliged to adopt some convention with regard to some of the prolonged earthquake-series. He reckoned "each month of such shocks as equivalent to one great earthquake."

Period.	Maximum.	Amplitude.
Annual	August, *b*	·11
Semi-annual	March, *a* September, *a*	·16

Sandwich Islands.

67. C. W. C. Fuchs, 'Statistik der Erdbeben,' pp. 404–408.
Duration of record, 1865–1882. Number of earthquakes, 245.

Period.	Maximum.	Amplitude.
Annual	June, *b*	·33
Semi-annual	{ February, *b* August, *b* }	·25

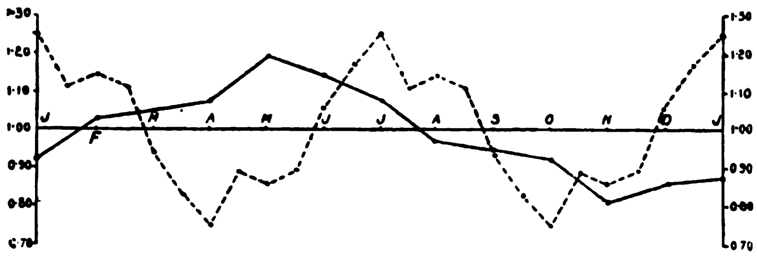
Buchan gives the results of two series of barometric observations at Honolulu. The first series gives the maximum epoch of the annual period in May, *b*; the second in April, *b*; the amplitudes, or semi-ranges, being ·025 and ·033 inch, respectively.

Seismic Periodicity in Countries near the Equator.

Malay Archipelago.

68. *C. W. C. Fuchs, 'Statistik der Erdbeben,' pp. 286–308.
Duration of record, 1865–1884. Number of earthquakes, 598.

Fig. 18.



Malay Archipelago (Fuchs).

Period.	Maximum.	Amplitude.
Annual	May, *b*	·19
Semi-annual	{ January, *a* July, *a* }	·25

The maximum of the annual barometric period occurs in March, *b*, at Buitenzorg; in August, *b*, at Batavia; and in September, *b*, at Padang.

69. C. G. KNOTT, 'Trans. of Seismol. Soc. of Japan,' vol. 9, pt. 1, 1886, Table A.*
Duration of record, 1873–1881. Number of earthquakes, 515.

Period.	Maximum.	Amplitude.
Annual	Irregular	
Semi-annual	March, *a* September, *a*	·11 but irregular

New Granada and Venezuela.

70. C. W. C. FUCHS, 'Statistik der Erdbeben,' pp. 347–356.
Duration of record, 1865–1884. Number of earthquakes, 272.

Period.	Maximum.	Amplitude.
Annual	February, *b*	·64
Semi-annual	March, *a*—March, *b* September, *a*—September, *b*	·27

The maximum epoch of the annual barometric period is very variable in different parts of the district, occurring as early as April in some parts and as late as September in others. The range is, however, very small.

SEISMIC PERIODICITY IN THE SOUTHERN HEMISPHERE.

Southern Hemisphere.

71. R. MALLET, 'Brit. Assoc. Rep.,' 1858, p. 57. (See also reference and note given in § 18.)
Duration of record, 1578–1850. Number of earthquakes, 223.

Period.	Maximum.	Amplitude.
Annual	November, *b*	·24
Semi-annual	May, *a* November, *a*	·33

* Dr. KNOTT quotes from a list by BERGSMA. The reference he gives is 'Natuurkundig Tijdschrift voor Nederlandsch-Indie.' I have not had an opportunity of seeing this work.

72. C. W. C. FUCHS, 'Statistik der Erdbeben,' pp. 312–317, 322–347, 356–357, 401–404.

Duration of record, 1865–1884. Number of earthquakes, 751.

The semi-annual period is not well-defined.

Period.	Maximum.	Amplitude.
Annual.	August, *b*	·37
Semi-annual	January, *a*—March, *a* July, *a*—September, *a*	·06
Annual barometric . . .	April, *b*—July, *b*	

New South Wales, Victoria, and South Australia.

73. G. HOGBEN, "Report of the Committee . . . appointed to investigate and report upon Seismological Phenomena in Australasia," 'Trans. Austral. Assoc. for the Adv. of Science,' vol. 4, 1892, pp. 8–27.

Duration of records: New South Wales, 1880–1891; Victoria, 1884–1891; South Australia, 1882–1891. Number of earthquakes: New South Wales, 24; Victoria, 60; South Australia, 75; total, 159.

Period.	Maximum.	Amplitude.
Annual.	May, *b*	·48
Semi-annual	February, *a* August, *a*	·43
Annual barometric . . .	May, *b* and June, *b*	

New Zealand.

74. *Sir J. HECTOR, "Report of the Committee . . . appointed to investigate and report upon Seismological Phenomena in Australasia," 'Trans. Austral. Assoc. for the Adv. of Science,' vol. 3, 1891, pp. 505–532.

Duration of record, 1868–1890. Number of earthquakes, 641 (fig. 19).

Period.	Maximum.	Amplitude.
Annual.	March, *b*—May, *b*	·05
Semi-annual	February, *a* August, *a*	·13
Annual barometric. . .	April, *b*	

75. In discussing the geographical distribution of the New Zealand earthquakes, Sir J. Hector has classified the earthquakes in monthly groups in six districts. The following are the results obtained from the numbers given by him :—

District I. North part of the North Island, including Hokianga, Kaipara, and Cambridge. Number of earthquakes, 2.

District II. Central part of the North Island, including Tauranga, Taupo, Taranaki, and Manawatu. Number of earthquakes, 184.

Period.	Maximum.	Amplitude.
Annual.	April, *b*	·22
Semi-annual	March, *a* September, *a*	·30

District III. East Coast of the North Island, including Gisborne, Napier, and Wellington. Number of earthquakes, 188.

Period.	Maximum.	Amplitude.
Annual.	May, *b*	·11
Semi-annual	February, *a* August, *a*	·26

District IV. West Coast of the South Island, including Marlborough, Nelson, and Grey. Number of earthquakes, 88.

Period.	Maximum.	Amplitude.
Annual.	July, *b*	·32
Semi-annual	March, *a* September, *a*	·20

District V. East Coast of the South Island, including Bealey, Christchurch, South Canterbury, Dunedin, and Southland. Number of earthquakes, 98.

Period.	Maximum.	Amplitude.
Annual	Irregular	
Semi-annual	March, *a* September, *a*	·28

District VI. South part of the South Island, including Central Otago. Number of earthquakes, 30.

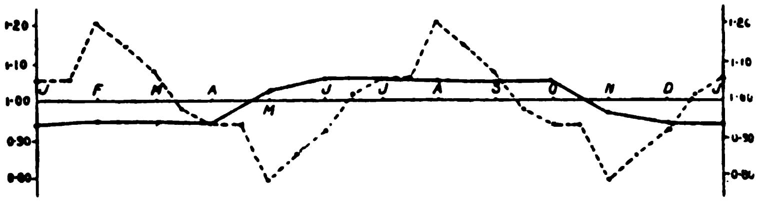
The number of earthquakes is far too small to yield trustworthy results.

Period.	Maximum.	Amplitude.
Annual	Irregular	
Semi-annual	May, *a* November, *a*	·56

76. *G. HOGBEN, "The Earthquakes of New Zealand." 'Trans. of the Austral. Assoc. for the Adv. of Science,' vol. 3, 1891, pp. 37–57; also, "Report of the Committee . . . appointed to investigate and report upon Seismological Phenomena in Australasia," vol. 4, 1892, pp. 28–33.

Duration of record, 1848–1891. Number of earthquakes, 737 (fig. 20).

Fig. 20.



New Zealand (HOGBEN).

Period.	Maximum.	Amplitude.
Annual	Between June, *b* and October, *b*	·06
Semi-annual	February, *a* August, *a*	·21

77. G. Hogben, *ibid.*, vol. 3, 1891, p. 44.

Duration of record, 1848–1890. Number of earthquakes, 745.

Counting slighter shocks, which would be reckoned together with the definition of the unit earthquake adopted in this paper, Mr. Hogben has given a table of the number of shocks felt in each month. The total number for the same years, obtained by myself, is 695. The result is to increase the amplitudes of both periods.

Period.	Maximum.	Amplitude.
Annual.	July, *b*	·14
Semi-annual	{ February, *a* / August, *a* }	·23

Chili.

78. A. Perrey, 'Brit. Assoc. Rep.', 1858, p. 27.

Duration of record, 16th to 19th centuries. Number of earthquakes, 178.

Perrey's district consists of Chili and La Plata, or, in Mallet's words, "the region lying between the western slope of the Andes and the sea, from the 24° to the 45° south latitude, between the Desert of Atacama on the north, and the Archipelago of Chonos on the south." The number of earthquakes recorded by Perrey is small, considering that, as Mallet remarks, the region is one "in which shocks of greater or less intensity are almost of daily occurrence."

Period.	Maximum.	Amplitude.
Annual.	August, *b*	·14
Semi-annual	Irregular	

79. C. W. C. Fuchs, 'Statistik der Erdbeben,' pp. 322–331.

Duration of record, 1865–1883. Number of earthquakes, 316.

For the first seven years (1865–1871) Fuchs' record is a full one. During the remainder of the time it is evidently very incomplete, there being five years (1875, 1877, 1878, 1881, 1882), without any disturbance recorded. This deprives the list of much of its value for statistical purposes.

The figures for both periods are very irregular. The maximum six-monthly mean (1·27) occurs at the end of August, but at the end of December it is 1·25, with much smaller values intervening. In like manner for the semi-annual period, the maximum six-half-monthly mean (1·11) occurs in the middle of April and October, but at the end of May and November it is 1·10.

80. C. G. KNOTT, 'Trans. of Seismol. Soc. of Japan,' vol. 9, pt. 1, 1886, Table A.*
Duration of record, 1873–1881. Number of earthquakes, 212.

Period.	Maximum.	Amplitude.
Annual.	August, *b*	·48
Semi-annual	June, *a* December, *a*	·17
Annual barometric . .	July, *b*	

Peru, Bolivia, and Quito.

81. C. W. C. FUCHS, 'Statistik der Erdbeben,' pp. 331–347.
Duration of record, 1865–1884. Number of earthquakes, 350.

Period.	Maximum.	Amplitude.
Annual.	July, *b*	·48
Semi-annual	January, *a* July, *a*	·24
Annual barometric . .	July, *b*	

* Dr. KNOTT quotes VERGARA as his authority, and gives as the reference 'Observaciones Meteorologicas' (Santiago), 1884 I have not been able to consult this work.

TABLE I.—Number of Earthquakes.

District.	Duration of record.	Catalogue.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Slight earthquakes	1785–1842	MALLET	8 14	7 7	7 5	6 9	4 9	8 7	12 12	11 9	10 6	6 7	6 6	6 5
Destructive earthquakes . . .	528–1842	”	33 32	29 29	22 33	36 28	21 26	38 11	16 28	24 28	32 17	26 31	21 31	22 27
Japanese earthquakes disturbing an area greater than 1000 sq. ri	1885–1889	Imp. Meteor. Bureau	15	21	11	21	16	13	11	10	17	13	16	12
Japanese earthquakes disturbing an area less than 1000 sq. ri and greater than 100 sq. ri	”	”	48	54	38	42	77	53	42	41	36	39	40	55
Japanese earthquakes disturbing an area less than 100 sq. ri	”	”	154	200	176	150	205	127	158	286	197	192	215	196
Northern hemisphere	223–1850	MALLET	627	539	503	489	438	428	415	488	463	516	473	500
* ” ”	1865–1884	FUCHS	342 409	344 338	403 405	286 269	345 285	242 256	269 321	237 244	252 318	343 422	487 505	437 374
*Europe	”	”	222 285	243 199	269 290	166 170	171 181	158 184	177 229	153 162	169 222	243 297	388 369	303 249
Europe and adjacent parts of Asia and Africa	306–1843	PERREY	228	189	172	147	126	131	148	147	147	176	148	202
Scandinavia and Iceland . . .	12th to 19th centuries	”	33	20	21	13	16	10	17	13	18	17	19	17
British Islands and Northern Isles	11th to 19th centuries	”	21	16	19	16	16	10	9	19	24	17	22	28
Great Britain	1608–1838	D. MILNE	7 12	15 11	6 8	4 8	6 4	7 5	5 2	6 11	11 13	10 9	12 16	6 12
” ”	1739–1888	ROPER	20 16	12 16	5 26	9 16	5 7	11 14	5 6	13 12	13 12	11 13	9 19	13 14

TABLE I.—Number of Earthquakes (continued).

District.	Duration of record.	Catalogue.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
France	1865–1884	FUCHS	2 13	9 5	12 9	8 3	1 10	1 7	3 8	9 3	11 8	9 5	6 31	7 13
France, Belgium, and Holland .	5th to 19th centuries	PERREY	83	64	53	55	42	36	47	40	50	48	60	78
Spain and Portugal	12th to 19th centuries	"	25	14	16	18	9	14	18	16	12	23	22	14
*Austria	1865–1884	FUCHS	19 34	28 13	32 10	13 22	24 25	15 14	13 12	5 12	12 15	11 22	22 32	28 28
*Hungary, Croatia, and Transylvania	"	"	21 21	17 11	21 15	7 9	23 17	12 28	2 6	6 10	14 13	16 15	26 24	37 13
*Switzerland and the Tyrol . .	"	"	26 36	26 24	24 22	13 24	13 18	11 15	21 26	12 8	12 13	11 11	26 42	45 45
Basin of the Rhone	16th to 19th centuries	PERREY	26	20	16	10	11	11	9	9	19	15	14	24
Basin of the Rhine and Switzerland	9th to 19th centuries	"	62	54	44	37	36	30	35	30	36	36	58	71
Basin of the Danube	5th to 19th centuries	"	31	31	14	16	23	19	26	25	16	23	18	26
Italy	"	"	101	99	98	84	80	86	63	77	63	92	64	77
"	1865–1883	FUCHS	93 89	75 67	103 152	75 79	73 78	89 89	93 138	81 78	80 119	141 118	121 115	121 83
Italy, without the district round Vesuvius and Sicily	"	"	49 69	54 37	74 63	57 60	45 49	44 50	74 71	36 40	60 78	103 95	78 79	91 57
*District round Vesuvius . . .	"	"	32 14	16 22	23 17	9 9	20 7	30 19	14 45	20 20	5 30	25 17	41 32	25 21
Sicily	"	"	12 6	5 8	6 72	9 10	8 22	15 20	5 22	25 18	15 11	13 6	2 4	5 5

TABLE I.—Number of Earthquakes (continued).

District.	Duration of record.	Catalogue.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
South-east of Europe, &c. . . .	4th to 19th centuries	PERREY	40	35	31	30	37	35	35	40	40	34	33	33
* ,, ,, . . .	1859–1877	SCHMIDT	88 174	233 133	165 173	161 113	119 92	119 118	91 125	201 144	107 124	231 220	170 114	110 141
*Balkan Peninsula and adjacent islands	1865–1884	FUCHS	16 36	56 34	50 41	34 17	18 31	19 17	23 28	30 17	15 34	43 32	25 22	23 20
*Zante	1825–1863	BARBIANI	37 40	54 47	41 56	43 44	53 63	72 88	59 62	61 52	44 41	41 52	72 58	75 71
,, ...	,,	BARBIANI'S monthly figures	80	107	105	89	131	176	141	131	91	165	279	168
,, ...	1859–1878	SCHMIDT and FUCHS	3 3	19 13	14 15	10 12	12 8	13 6	4 9	2 11	7 9	22 16	9 9	7 17
Algeria	1865–1883	FUCHS	25 11	11 5	5 5	5 2	10 1	2 2	6 2	1 2	4 2	6 6	3 16	3 0
Asia	1865–1884	,,	27 25	9 42	17 26	18 29	25 15	10 14	17 15	22 14	16 20	9 10	18 17	30 13
Caucasia	,,	,,	4 15	0 28	2 12	5 14	6 2	2 4	7 4	6 2	6 8	1 2	2 8	10 2
Japan	1885–1889	Imp. Met. Bur. of Japan	217	275	225	213	298	193	211	337	250	244	271	263
*Tokio	1876–1881 and 1883–1891	J. MILNE	33 52	41 57	53 43	37 59	61 61	42 35	32 41	34 31	34 28	45 68	39 59	52 67

TABLE I.—Number of Earthquakes (continued).

District.	Duration of record.	Catalogue.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Tokio	1876–1881 1883–1884 and 1886–1891	J. MILNE	30 48	35 54	51 37	36 56	59 60	38 33	32 41	34 28	31 23	39 64	38 57	48 64
,, ...	1878–1881	,,	10 21	14 16	20 9	7 7	13 7	12 6	5 13	4 8	4 2	7 10	13 10	11 17
Yokohama	,,	STREETS	8 13	8 10	12 8	4 5	6 3	5 4	4 8	4 3	1 1	3 8	6 3	2 6
*India.	1803–1869	OLDHAM	27 18	15 9	6 14	10 13	7 9	13 12	13 11	14 35	11 10	13 14	6 8	9 23
*North America	1865–1884	FUCHS	26 23	27 13	22 21	23 19	14 17	12 13	25 16	14 19	21 26	36 52	28 23	19 43
United States and Canada . . .	17th to 19th centuries	PERREY	14	14	12	6	6	4	10	14	8	10	19	17
New England	1638–1869	BRIGHAM	13 15	18 11	8 8	3 5	3 11	10 3	11 4	8 5	8 2	8 11	17 10	11 9
*California, &c.	1850–1886	HOLDEN	40 52	38 16	29 51	48 34	28 33	28 19	39 18	30 33	38 41	55 66	43 40	54 67
,, ...	,,	HOLDEN'S monthly figures	68	45	66	71	56	51	45	53	85	88	57	83
San Francisco	,,	HOLDEN	25	22	26	15	17	17	13	11	21	35	30	22
San José and Santa Clara . . .	,,	,,	2	7	5	3	2	1	4	4	4	9	8	5
Mexico	1865–1882	FUCHS	4 1	2 4	5 6	1 3	13 7	1 1	0 1	1 2	0 1	1 23	4 1	2 2

TABLE I.—Number of Earthquakes (continued).

District.	Duration of record.	Catalogue.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Central America	1865–1884	FUCHS	6 5	8 7	15 13	14 7	6 8	13 6	8 9	5 5	9 9	8 3	9 9	1 7
West Indies.	1865-1883	"	5 17	5 7	3 7	9 1	2 5	10 4	6 5	7 9	6 9	1 5	6 30	39 7
"	16th to 19th centuries	PERREY	15	16	23	17	16	16	20	23	22	20	18	15
Sandwich Islands.	1865–1882	FUCHS	6 7	8 14	6 11	20 6	13 20	11 6	3 15	16 13	16 10	5 7	7 11	9 5
*Malay Archipelago	1865–1884	"	28 27	23 24	21 32	20 23	18 36	36 21	20 45	30 42	15 26	21 13	15 16	27 29
" "	1873–1881	BERGSMA	47	41	51	39	31	52	36	52	36	54	36	40
New Granada and Venezuela . .	1865–1884	FUCHS	6 8	13 20	38 13	14 22	10 15	9 9	7 5	5 5	6 9	9 4	9 5	17 14
Southern hemisphere . . .	1578–1850	MALLET	19	14	9	17	20	19	18	12	17	25	32	21
" "	1865–1884	FUCHS	35 25	24 23	23 35	23 23	22 20	40 45	33 43	41 47	27 23	48 53	31 33	18 16
New South Wales, Victoria, and South Australia	1880–1891	HOGBEN	3 3	3 6	9 17	5 3	6 4	9 7	14 10	13 7	8 8	6 6	3 3	4 2
*New Zealand	1868–1890	HECTOR	29 23	36 25	34 29	19 30	31 21	31 22	20 33	33 29	27 28	18 27	22 24	28 22
" " District II. . . .	"	"	12	19	26	17	10	12	20	14	13	19	11	11

TABLE I.—Number of Earthquakes (continued).

District.	Duration of record.	Catalogue.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
New Zealand, District III. . .	1868–1890	HECTOR	19	15	19	16	11	17	18	20	18	6	14	15
,, District IV. . .	,,	,,	5	5	7	7	8	5	10	10	10	10	4	7
,, ,, District V. . . .	,,	,,	8	10	9	7	7	10	3	11	9	11	5	8
,, ,, District VI. . .	,,	,,	3	1	0	6	2	2	0	5	1	3	5	2
*New Zealand	1848–1891	HOGBEN	31 38	28 27	32 37	23 27	29 29	28 25	30 35	42 41	29 46	25 26	24 28	33 24
,, ,, ...	1848–1890	HOGBEN'S monthly figures.	67	52	70	47	56	67	67	79	88	51	50	51
Chili	16th to 19th centuries	PERREY	15	12	16	8	21	12	16	16	16	10	27	9
,, ...	1865–1883	FUCHS	15 13	16 12	12 17	4 12	11 8	14 14	11 16	13 11	10 9	15 28	26 18	4 7
,, ...	1873–1881	VERGARA	13	6	7	13	18	20	26	25	23	20	24	17
Peru, Bolivia, and Quito . . .	1865–1884	FUCHS	15 11	5 10	10 15	16 9	10 11	17 27	19 27	21 30	15 13	23 15	3 9	13 6

TABLE II.—Annual Seismic Period.

District.	Duration of record.	Catalogue.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Slight earthquakes	1785–1842	MALLET	0·89	0·89	0·97	1·00	1·08	1·16	1·11	1·11	1·03	1·00	0·92	0·84
Destructive earthquakes . . .	528–1842	„	1·13	1·10	1·10	1·00	0·94	0·92	0·87	0·90	0·90	1·00	1·06	1·08
Japanese earthquakes, disturbing an area greater than 1000 sq. ri	1885–1889	Imp. Met. Bur. of Japan	1·16	1·16	1·17	1·11	0·87	0·98	0·84	0·84	0·83	0·89	1·13	1·02
Japanese earthquakes, disturbing an area less than 1000 sq. ri and greater than 100 sq. ri	„	„	0·98	1·17	1·17	1·14	1·05	1·03	1·02	0·83	0·83	0·86	0·95	0·97
Japanese earthquakes, disturbing an area less than 100 sq. ri	„	„	0·97	0·95	0·86	0·86	0·94	0·98	1·03	1·05	1·14	1·14	1·06	1·02
Northern hemisphere	223–1850	MALLET	1·11	1·08	1·05	0·94	0·89	0·89	0·89	0·92	0·95	1·06	1·11	1·11
* „ „	1865–1884	FUCHS	1·22	1·06	0·95	0·89	0·79	0·71	0·78	0·94	1·05	1·11	1·21	1·29
*Europe	„	„	1·24	1·00	0·89	0·83	0·73	0·65	0·76	1·00	1·11	1·17	1·27	1·35
Europe, and adjacent parts of Asia and Africa	306–1843	PERREY	1·19	1·14	1·03	0·90	0·81	0·78	0·83	0·86	0·97	1·10	1·19	1·22
Scandinavia and Iceland . . .	12th to 19th centuries	„	1·25	1·19	1·10	0·87	0·73	0·70	0·75	0·81	0·90	1·14	1·27	1·30
British Islands and Northern Isles	11th to 19th centuries	„	1·21	1·11	0·86	0·68	0·70	0·79	0·79	0·89	1·14	1·32	1·30	1·21
Great Britain	1608–1838	D. MILNE	1·22	0·94	0·86	0·68	0·51	0·67	0·78	1·06	1·14	1·32	1·49	1·33
„ „	1739–1888	ROPER	1·29	1·11	1·10	0·84	0·78	0·73	0·71	0·89	0·90	1·16	1·22	1·27
France	1865–1884	FUCHS	1·37	0·92	0·73	0·67	0·62	0·59	0·63	1·08	1·27	1·33	1·38	1·41
France, Belgium, and Holland .	5th to 19th centuries	PERREY	1·33	1·24	1·03	0·87	0·73	0·72	0·67	0·76	0·97	1·13	1·27	1·29

TABLE II.—Annual Seismic Period (continued).

District.	Duration of record.	Catalogue.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Spain and Portugal	12th to 19th centuries	PERREY	1·14	0·94	0·94	0·83	0·84	0·79	0·86	1·06	1·06	1·17	1·16	1·21
*Austria	1865–1884	FUCHS	1·37	1·32	1·14	0·95	0·76	0·67	0·63	0·68	0·86	1·05	1·24	1·33
*Hungary, Croatia, and Transylvania	„	„	1·25	1·16	1·10	0·81	0·70	0·62	0·75	0·84	0·90	1·19	1·30	1·38
*Switzerland and the Tyrol	„	„	1·56	1·33	0·95	0·86	0·65	0·54	0·44	0·67	1·05	1·14	1·35	1·46
Basin of the Rhone	16th to 19th centuries	PERREY	1·32	1·25	1·05	0·76	0·54	0·60	0·68	0·75	0·95	1·24	1·46	1·40
Basin of the Rhine and Switzerland	9th to 19th centuries	„	1·38	1·24	1·00	0·84	0·67	0·63	0·62	0·76	1·00	1·16	1·33	1·37
Basin of the Danube	5th to 19th centuries	„	1·05	1·10	1·02	0·97	0·86	0·89	0·95	0·90	0·98	1·05	1·14	1·11
Italy	„	„	1·11	1·16	1·19	1·08	0·97	0·87	0·88	0·84	0·81	0·92	1·03	1·10
„	1865–1883	FUCHS	1·00	0·89	0·86	0·92	0·92	0·86	1·00	1·11	1·14	1·08	1·08	1·14
Italy, without the district round Vesuvius and Sicily	„	„	1·03	0·89	0·79	0·84	0·79	0·81	0·97	1·11	1·21	1·16	1·21	1·19
*District round Vesuvius	„	„	1·05	0·75	0·78	0·84	0·84	0·81	0·95	1·25	1·22	1·16	1·16	1·19
Sicily	„	„	0·81	1·05	1·30	1·38	1·67	1·19	1·19	0·95	0·70	0·62	0·33	0·81
Florence, microseismic intensity (old tromometer)	Dec. 1872—Nov. 1887	BERTELLI	1·48	1·35	1·06	0·83	0·63	0·51	0·52	0·65	0·94	1·17	1·37	1·49
Florence, microseismic intensity (old tromometer)	Dec. 1876—Nov. 1887	„	1·44	1·30	1·05	0·79	0·63	0·54	0·56	0·70	0·95	1·21	1·37	1·46
Florence, microseismic intensity (normal tromometer)	„	„	1·43	1·27	0·98	0·73	0·59	0·51	0·57	0·73	1·02	1·27	1·41	1·49
South-east of Europe, &c.	4th to 19th centuries	PERREY	0·94	0·97	0·98	0·95	0·97	1·03	1·06	1·03	1·02	1·05	1·03	0·97

TABLE II.—Annual Seismic Period (continued).

District.	Duration of record.	Catalogue.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
*South-east of Europe, &c.	1859–1877	SCHMIDT	1·05	0·98	0·98	0·94	0·89	0·79	0·95	1·02	1·02	1·06	1·11	1·21
*Balkan Peninsula and adjacent islands	1865–1884	FUCHS	1·17	1·17	1·14	1·14	0·90	0·73	0·83	0·83	0·86	0·86	1·10	1·27
*Zante	1825–1863	BARBIANI	0·95	0·90	0·95	1·06	1·06	1·05	1·05	1·10	1·05	0·94	0·94	0·95
,,	,,	BARBIANI'S monthly numbers	1·02	0·71	0·73	0·86	0·86	0·84	0·98	1·29	1·27	1·14	1·14	1·16
,,	1859–1878	SCHMIDT and FUCHS	1·10	1·11	1·06	1·14	0·87	0·71	0·90	0·89	0·94	0·86	1·13	1·29
Algeria	1865–1883	FUCHS	1·57	1·38	1·40	0·75	0·41	0·33	0·43	0·62	0·60	1·25	1·59	1·67
Asia	1865–1884	,,	1·30	1·33	1·21	1·06	0·94	0·90	0·70	0·67	0·79	0·94	1·06	1·10
Caucasia	,,	,,	1·56	1·51	1·38	1·22	0·78	0·79	0·44	0·49	0·62	0·78	1·22	1·21
Japan	1885–1889	Imp. Met. Bur. of Japan	0·98	1·00	0·94	0·92	0·97	1·00	1·02	1·00	1·06	1·08	1·03	1·00
*Tokio	1876–1881 and 1883–1891	J. MILNE	1·13	1·19	1·08	1·05	0·92	0·84	0·87	0·81	0·92	0·95	1·08	1·16
,,	1876–1881 1883–1884 and 1886–1891	,,	1·13	1·19	1·08	1·06	0·95	0·86	0·87	0·81	0·92	0·94	1·05	1·14
,,	1878–1881	,,	1·43	1·38	1·27	1·10	0·84	0·54	0·57	0·62	0·73	0·90	1·16	1·46
Yokohama	,,	STREETS	1·38	1·38	1·41	1·32	1·02	0·59	0·62	0·62	0·59	0·68	0·98	1·41
*India	1803–1869	OLDHAM	0·98	1·00	0·95	0·75	0·95	0·98	1·02	1·00	1·05	1·25	1·05	1·02

TABLE II.—Annual Seismic Period (continued).

District.	Duration of record.	Catalogue.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
*North America	1865–1884	FUCHS	1·08	0·95	0·75	0·71	0·65	0·68	0·92	1·05	1·25	1·29	1·35	1·32
United States and Canada	17th to 19th centuries	PERREY	1·36	1·05	0·75	0·67	0·64	0·54	0·64	0·95	1·25	1·33	1·36	1·46
New England	1638–1869	BRIGHAM	1·35	1·14	1·05	0·86	0·59	0·49	0·65	0·86	0·95	1·14	1·41	1·51
*California, &c.	1850–1886	HOLDEN	1·16	1·08	0·84	0·70	0·71	0·71	0·84	0·92	1·16	1·30	1·29	1·29
„	„	HOLDEN'S monthly figures	1·03	1·02	0·90	0·81	0·83	0·90	0·97	0·98	1·10	1·19	1·17	1·10
San Francisco	„	HOLDEN	1·17	1·00	0·95	0·79	0·63	0·59	0·83	1·00	1·05	1·21	1·37	1·41
San José and Santa Clara	„	„	1·21	0·83	0·60	0·71	0·51	0·44	0·79	1·17	1·40	1·29	1·49	1·56
Mexico	1865–1882	FUCHS	0·73	1·29	1·21	1·06	0·94	0·57	1·27	0·71	0·79	0·94	1·06	1·43
Central America	1865–1884	„	1·11	1·03	1·22	1·32	1·22	1·06	0·89	0·97	0·78	0·68	0·78	0·94
West Indies	1865–1883	„	1·52	1·06	0·57	0·41	0·46	0·54	0·48	0·94	1·43	1·59	1·54	1·46
„ „	16th to 19th centuries	PERREY	0·92	0·89	0·90	0·97	1·05	1·05	1·08	1·11	1·10	1·03	0·95	0·95
Sandwich Islands	1865–1882	FUCHS	0·86	1·03	1·08	1·14	1·21	1·33	1·14	0·97	0·92	0·86	0·79	0·67
*Malay Archipelago	1865–1884	„	0·92	1·03	1·05	1·08	1·19	1·14	1·08	0·97	0·95	0·92	0·81	0·86
„ „	1873–1881	BERGSMA	0·98	0·95	1·03	0·97	1·02	0·92	1·02	1·05	0·97	1·03	0·98	0·92
New Granada and Venezuela	1865–1884	FUCHS	1·51	1·64	1·49	1·48	1·17	0·76	0·49	0·36	0·51	0·52	0·83	1·24
Southern hemisphere	1578–1850	MALLET	1·02	0·84	0·83	0·81	0·76	0·87	0·98	1·16	1·17	1·19	1·24	1·13

TABLE II.—Annual Seismic Period (continued).

District.	Duration of record.	Catalogue.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Southern hemisphere	1865–1884	FUCHS	0·73	0·63	0·86	0·92	1·06	1·05	1·27	1·37	1·14	1·08	0·94	0·95
New South Wales, Victoria, and South Australia	1880–1891	HOGBEN	0·63	0·71	0·92	1·27	1·48	1·29	1·37	1·29	1·08	0·73	0·52	0·71
*New Zealand	1868–1890	HECTOR	1·00	1·03	1·05	1·05	1·05	1·02	1·00	0·97	0·95	0·95	0·95	0·98
„ „ District II. . .	„	„	1·08	1·06	1·08	1·22	1·11	0·89	0·92	0·94	0·92	0·78	0·89	1·11
„ „ „ III. . .	„	„	1·08	1·02	1·06	1·05	1·11	1·10	0·92	0 98	0·94	0·95	0·89	0·90
„ „ „ IV. . .	„	„	0·68	0·83	0·76	0·94	1·10	1·22	1·32	1·17	1·24	1·06	0·90	0·78
„ „ „ V. . .	„	„	0·95	1·00	1·08	0·92	0·92	0·94	1·05	1·00	0·92	1·08	1·08	1·06
„ „ „ VI. . .	„	„	1·22	0·90	0·90	0·59	1·00	1·11	0·78	1·10	1·10	1·41	1·00	0·89
*New Zealand	1848–1891	HOGBEN	0·94	0·95	0·95	0·94	1·03	1·06	1·06	1·05	1·05	1·06	0·97	0·94
„ „	1848–1890	HOGBEN'S monthly numbers	0·86	0·87	0·95	0·95	1·05	1·13	1·14	1·13	1·05	1·05	0·95	0·87
Chili	16th to 19th centuries	PERREY	0·98	0·86	0·92	0·94	0·98	1·00	1·02	1·14	1·08	1·06	1·02	1·00
„	1865–1883	FUCHS	1·00	0·73	0·92	0·90	0·84	0·75	1·00	1·27	1·08	1·10	1·16	1·25
„	1873–1881	VERGARA	0·62	0·52	0·57	0·76	1·03	1·29	1·38	1·48	1·43	1·24	0·97	0·71
Peru, Bolivia, and Quito . . .	1865–1884	FUCHS	0·52	0·60	0·84	1·02	1·32	1·37	1·48	1·40	1·16	0·98	0·68	0·63

TABLE III.—Semi-Annual Seismic Period.

District.	Duration of record.	Catalogue.	Jan.–July. a.	Jan.–July. b.	Feb.–Aug. a.	Feb.–Aug. b.	Mar.–Sept. a.	Mar.–Sept. b.	April.–Oct. a.	April.–Oct. b.	May.–Nov. a.	May.–Nov. b.	June.–Dec. a.	June.–Dec. b.
Slight earthquakes	1785–1842	MALLET	1·21	1·27	1·25	1·11	0·95	0·81	0·79	0·73	0·75	0·89	1·05	1·19
Destructive earthquakes	528–1842	"	0·98	0·95	1·02	1·08	1·08	1·02	1·02	1·05	0·98	0·92	0·92	0·98
Japanese earthquakes disturbing an area greater than 1000 sq. ri	1885–1889	Imp. Met. Bur. of Japan	0·90		0·95		1·12		1·10		1·05		0·88	
Japanese earthquakes disturbing an area less than 1000 sq. ri and greater than 100 sq. ri	"	"	1·07		0·87		0·84		0·93		1·13		1·16	
Japanese earthquakes disturbing an area less than 100 sq. ri	"	"	0·98		1·07		1·12		1·02		0·93		0·88	
Northern hemisphere	223–1850	MALLET	1·03		1·07		1·05		0·97		0·93		0·95	
* " "	1865–1884	FUCHS	0·90	0·89	0·94	0·94	0·94	1·02	1·10	1·11	1·06	1·06	1·06	0·98
*Europe	"	"	0·89	0·89	0·92	0·94	0·92	1·00	1·11	1·11	1·08	1·06	1·08	1·00
Europe and adjacent parts of Asia and Africa	306–1843	PERREY	1·12		1·10		1·02		0·88		0·90		0·98	
Scandinavia and Iceland	12th to 19th centuries	"	1·05		1·22		0·94		0·95		0·78		1·06	
British Islands and Northern Isles	11th to 19th centuries	"	0·92		1·00		1·05		1·08		1·00		0·95	
Great Britain	1608–1838	D. MILNE	0·94	1·00	1·06	1·10	1·16	1·10	1·06	1·00	0·94	0·90	0·84	0·90
"	1739–1888	ROPER	1·05	0·98	1·08	1·03	1·11	0·98	0·95	1·02	0·92	0·97	0·89	1·02
France	1865–1884	FUCHS	0·73	0·97	0·94	1·13	0·94	0·73	1·27	1·03	1·06	0·87	1·06	1·27
France, Belgium, and Holland . .	5th to 19th centuries	PERREY	1·10		1·05		0·94		0·90		0·95		1·06	
Spain and Portugal	12th to 19th centuries	"	1·02		1·00		0·98		0·98		1·00		1·02	
*Austria	1865–1884	FUCHS	0·94	0·94	0·83	0·78	0·78	0·86	1·06	1·06	1·17	1·22	1·22	1·14

TABLE III.—Semi-Annual Seismic Period (continued).

District.	Duration of record.	Catalogue.	Jan.–July. a.	Jan.–July. b.	Feb.–Aug. a.	Feb.–Aug. b.	Mar.–Sept. a.	Mar.–Sept. b.	April–Oct. a.	April–Oct. b.	May–Nov. a.	May–Nov. b.	June–Dec. a.	June–Dec. b.
*Hungary, Croatia, and Transylvania	1865–1884	FUCHS	0·94	0·83	0·71	0·71	0·70	0·90	1·06	1·17	1·29	1·29	1·30	1·10
*Switzerland and the Tyrol . . .	"	"	1·21	1·08	0·94	0·79	0·65	0·63	0·79	0·92	1·06	1·21	1·35	1·37
Basin of the Rhone	16th to 19th centuries	PERREY	1·13		1·13		0·95		0·87		0·87		1·03	
Basin of the Rhine and Switzerland	9th to 19th centuries	"	1·12		0·98		0·85		0·88		1·02		1·15	
Basin of the Danube	5th to 19th centuries	"	1·30		1·12		0·90		0·70		0·88		1·10	
Italy	"	"	1·05		1·03		1·08		0·95		0·97		0·92	
"	1865–1883	FUCHS	0·90	0·86	0·98	1·03	1·00	1·05	1·10	1·14	1·02	0·97	1·00	0·95
Italy without the district round Vesuvius and Sicily	"	"	0·83	0·83	0·89	0·97	1·02	1·08	1·17	1·17	1·11	1·03	0·98	0·92
*District round Vesuvius	"	"	1·13	0·97	1·00	0·94	0·75	0·89	0·87	1·03	1·00	1·06	1·25	1·11
Sicily	"	"	0·86	0·87	1·41	1·46	1·35	1·14	1·14	1·13	0·59	0·54	0·65	0·86
Florence, microseismic intensity (old tromometer)	Dec. 1872—Nov. 1887	BERTELLI	0·98		0·97		1·00		1·02		1·03		1·00	
" " "	Dec. 1876—Nov. 1887	"	0·97		0·96		1·00		1·03		1·04		1·00	
Florence (normal tromometer) . .	"	"	1·00		0·92		0·92		1·00		1·08		1·08	
South-east of Europe, &c. . . .	4th to 19th centuries	PERREY	1·05		1·08		1·00		0·95		0·92		1·00	
* " " " . . .	1859–1877	SCHMIDT	0·95	1·00	1·03	1·22	1·25	1·11	1·05	1·00	0·97	0·78	0·75	0·89
*Balkan Peninsula and adjacent islands	1865–1884	FUCHS	0·92	1·02	1·19	1·37	1·32	1·10	1·08	0·98	0·81	0·73	0·68	0·90
*Zante	1825–1863	BARBIANI	1·14	0·98	0·84	0·81	0·81	0·81	0·86	1·02	1·16	1·19	1·19	1·19

TABLE III.—Semi-Annual Seismic Period (continued).

District.	Duration of record.	Catalogue.	Jan.–July. a.	Jan.–July. b.	Feb.–Aug. a.	Feb.–Aug. b.	Mar.–Sept. a.	Mar.–Sept. b.	April–Oct. a.	April–Oct. b.	May–Nov. a.	May–Nov. b.	June–Dec. a.	June–Dec. b.
Zante	1825–1863	BARBIANI'S monthly numbers	0·95		0·65		0·72		1·05		1·35		1·28	
"	1859–1878	SCHMIDT and FUCHS	0·78	0·79	0·81	1·13	1·33	1·32	1·22	1·21	1·19	0·87	0·67	0·68
Algeria	1865–1883	FUCHS	1·06	1·16	1·27	0·81	0·70	0·70	0·94	0·84	0·73	1·19	1·30	1·30
Asia	1865–1884	"	1·06	1·02	1·14	1·03	1·03	1·11	0·94	0·98	0·86	0·97	0·97	0·89
Caucasia	"	"	1·17	1·10	1·38	1·27	1·24	1·27	0·83	0·90	0·62	0·73	0·76	0·73
Japan	1885–1889	Imp. Met. Bur. of Japan	1·00		1·02		1·07		1·00		0·98		0·93	
*Tokio	1876–1881 and 1883–1891	J. MILNE	0·90	0·89	0·79	0·84	0·95	1·02	1·10	1·11	1·21	1·16	1·05	0·98
"	1876–1881 1883–1884 and 1886–1891	"	0·90	0·89	0·78	0·83	0·92	1·00	1·10	1·11	1·22	1·17	1·08	1·00
"	1878–1881	"	1·17	1·19	1·05	1·03	0·83	0·92	0·83	0·81	0·95	0·97	1·17	1·08
Yokohama	"	STREETS	1·13	1·29	1·25	1·25	1·08	1·06	0·87	0·71	0·75	0·75	0·92	0·94
*India	1803–1869	OLDHAM	1·38	1·33	1·24	1·06	1·05	0·87	0·62	0·67	0·76	0·94	0·95	1·13
*North America	1865–1884	FUCHS	0·86	0·92	0·87	0·92	1·11	1·10	1·14	1·08	1·13	1·08	0·89	0·90
United States and Canada	17th to 19th centuries	PERREY	1·15		1·13		0·93		0·85		0·87		1·07	
New England	1638–1869	BRIGHAM	1·19	1·11	1·10	0·89	0·86	0·75	0·81	0·89	0·90	1·11	1·14	1·25
*California, &c.	1850–1886	HOLDEN	0·89	0·84	0·87	0·92	1·02	1·03	1·11	1·16	1·13	1·08	0·90	0·97

TABLE III.—Semi-Annual Seismic Period (continued).

District.	Duration of record.	Catalogue.	Jan.–July. a.	Jan.–July. b.	Feb.–Aug. a.	Feb.–Aug. b.	Mar.–Sept. a.	Mar.–Sept. b.	April–Oct. a.	April–Oct. b.	May–Nov. a.	May–Nov. b.	June–Dec. a.	June–Dec. b.
California, &c.	1850–1886	HOLDEN's monthly numbers	0·84		0·92		1·12		1·16		1·08		0·88	
San Francisco	"	"	0·79		0·88		1·05		1·21		1·12		0·95	
San José and Santa Clara	"	"	0·77		0·97		1·33		1·23		1·03		0·67	
Mexico	1865–1882	FUCHS	0·21	0·28	0·43	0·35	1·21	1·73	1·79	1·72	1·57	1·65	0·79	0·27
Central America	1865–1884	"	0·75	0·92	1·06	1·21	1·14	1·17	1·25	1·08	0·94	0·79	0·86	0·83
West Indies	1865–1883	"	1·29	0·65	0·73	0·71	0·49	0·41	0·71	1·35	1·27	1·29	1·51	1·59
"	16th to 19th centuries	PERREY	0·93		1·13		1·16		1·08		0·87		0·84	
Sandwich Islands	1865–1882	FUCHS	0·89	0·90	1·03	1·25	1·14	1·08	1·11	1·10	0·97	0·75	0·86	0·92
*Malay Archipelago	1865–1884	"	1·25	1·11	1·14	1·11	0·94	0·83	0·75	0·89	0·86	0·89	1·06	1·17
" "	1873–1881	BERGSMA	1·06		1·03		1·11		0·94		0·97		0·89	
New Granada and Venezuela	1865–1884	FUCHS	0·79	1·02	1·00	1·11	1·27	1·27	1·21	0·98	1·00	0·89	0·73	0·73
Southern hemisphere	1578–1850	MALLET	0·87		0·67		0·75		1·13		1·33		1·25	
" "	1865–1884	FUCHS	1·06	1·03	1·02	1·03	1·06	1·00	0·94	0·97	0·98	0·97	0·94	1·00
New South Wales, Victoria, and South Australia	1880–1891	HOGBEN	1·03	1·13	1·43	1·30	1·24	1·08	0·97	0·87	0·57	0·70	0·76	0·92
*New Zealand	1868–1890	HECTOR	1·05	1·06	1·13	1·06	1·08	1·00	0·95	0·94	0·87	0·94	0·92	1·00
" District II.	"	"	0·93		1·21		1·30		1·07		0·79		0·70	
" " III.	"	"	1·18		1·26		1·02		0·82		0·74		0·98	

TABLE III.—Semi-Annual Seismic Period (continued).

District.	Duration of record.	Catalogue.	Jan.-July. a.	Jan.-July. b.	Feb.-Aug. a.	Feb.-Aug. b.	Mar.-Sept. a.	Mar.-Sept. b.	April-Oct. a.	April-Oct. b.	May-Nov. a.	May-Nov. b.	June-Dec. a.	June-Dec. b.
*New Zealand, District IV. . . .	1868–1890	HECTOR	0·92		1·12		1·20		1·08		0·88		0·80	
„ „ V. . . .	„	„	1·05		1·05		1·28		0·95		0·95		0·72	
„ „ VI. . . .	„	„	0·67		0·44		1·12		1·23		1·56		0·88	
* „	1848–1891	HOGBEN	1·06	1·06	1·21	1·14	1·08	0·98	0·94	0·94	0·79	0·86	0·92	1·02
„	1848–1890	HOGBEN'S monthly numbers	1·05		1·23		1·08		0·95		0·77		0·92	
Chili	16th to 19th centuries	PERREY	0·84		1·03		0·80		1·16		0·95		1·20	
„	1865–1883	FUCHS	0·89	0·94	0·97	0·90	1·02	1·08	1·11	1·06	1·03	1·10	0·98	0·92
„	1873–1881	VERGARA	1·02		0·90		0·83		0·98		1·10		1·17	
Peru, Bolivia, and Quito	1865–1884	FUCHS	1·24	1·19	1·14	1·19	1·06	0·94	0·76	0·81	0·86	0·81	0·94	1·06

Summary of Results.

82. *Annual Period.*—The number of seismic records examined is 62, 45 belonging to the northern hemisphere, 14 to the southern, and 3 to equatorial countries. Only five fail to indicate a fairly well-marked annual period, namely, South-east Europe (Perrey), East Indies (Bergsma), New Zealand, Districts V. and VI. (Hector), and Chili (Fuchs); and in all these cases the failure may, I think, be attributed to incompleteness in the seismic record. Different lists for the same district do not always give the same date for the maximum epoch, though in most cases they agree closely enough. The principal exceptions are Italy, Zante, Japan, West Indies, and the Southern Hemisphere; and in the three first of these districts the discrepancy may, perhaps, be explained. Excluding these somewhat doubtful cases, the distribution in time of the maximum epochs is given in the following table:—

	Northern hemisphere.	Equatorial countries.	Southern hemisphere.
January	6	0	0
February	1	1	0
March	0	0	0
April	1	0	2
May	1	1	2
June	1	0	0
July	0	0	3
August	1	0	2
September	0	0	0
October	3	0	0
November	4	0	0
December	16	0	0

These figures strongly support the view that *the maximum of the annual period occurs during the local winter in each hemisphere.* The evidence for equatorial countries is somewhat scanty, but it shows that in them, also, there is a well-marked annual period. If we were to include the two districts of India and Peru, Bolivia and Quito as equatorial, this conclusion will be further strengthened, the date of the maximum epoch being variable.

83. In amplitude, the results given by different lists for the same districts are more variable; and this is due in a great measure, I believe, to different definitions of the unit earthquake. This is especially shown in three cases in which the periodicity has been investigated both with my own definition and with that adopted by the cataloguer (§§ 45, 46, 59, 60, 76, 77).

The amplitude of the annual period ranges from ·05 (New Zealand) to ·67 (Sicily and Algeria). The average amplitude obtained from 57 records is ·33; the corresponding ratio of the number of shocks in the maximum and mininum halves of the year is 1·53, or, roughly, 3 : 2.

84. It will be seen, on examining the above tables, that the amplitude of the annual period is small in several countries which are generally regarded as earthquake countries. In some cases, this is no doubt due to the definition of the unit earthquake. Again, when the area is a wide one, the amplitude may be small, owing to the maximum epoch for different districts occurring at different dates. Partly to this, perhaps, is due the apparently small amplitude in the Northern Hemisphere (MALLET), Italy (FUCHS), and New Zealand (HECTOR and HOGBEN). Lastly, the amplitude is small in some insular districts, for example, Japan (·08) and New Zealand (·05 or ·06).

85. *Semi-Annual Period.*—Of the 62 records examined, only three fail to show a fairly well-marked semi-annual period, namely, France (FUCHS), Spain and Portugal (PERREY), and Chili (FUCHS); these failures also being probably due to incompleteness in the seismic record. Different records for the same district do not always agree in giving the same epoch for the maximum of the semi-annual period; for example, those of the Northern and Southern Hemispheres, Europe and the West Indies. As a rule, however, the agreement is fairly close. And this is also especially true in the case of districts adjoining and overlapping one another; for example, Austria, Hungary, and Switzerland and the Tyrol (FUCHS); South-east Europe (PERREY, SCHMIDT) and the Balkan Peninsula (FUCHS); California, San Francisco, and San José and Santa Clara (HOLDEN); India (OLDHAM) and the Malay Archipelago (FUCHS); the different districts of New Zealand (HECTOR); and also Tokio (MILNE) and Yokohama (STREETS), for the short period 1878–1881. Excluding doubtful cases, the distribution in time of the maximum epochs is given in the following table:—

	Northern hemisphere.	Equatorial countries.	Southern hemisphere.
January, *a*, and July, *a* . . .	4	1	1
January, *b*, and July, *b* . . .	0	0	0
February, *a*, and August, *a* . .	4	0	4
February, *b*, and August *b* . .	3	0	0
March, *a*, and September, *a* . .	5	1	3
March, *b*, and September, *b* . .	0		0
April, *a*, and October, *a* . . .	5	0	0
April, *b*, and October, *b* . . .	2	0	0
May, *a*, and November, *a* . . .	0	0	1
May, *b*, and November, *b* . . .	0	0	0
June, *a*, and December, *a* . .	3	0	1
June, *b*, and December *b* . . .	2	0	0

In New Zealand and the south-east of Australia, the maximum epoch falls most frequently in February or March, and August or September; in North America it usually occurs in March or April and September or October. I have not been able

to find any general rule in other cases, and it is possible that the materials are too imperfect to allow any law to be deduced.

86. The amplitude of the semi-annual period ranges from ·06 (Southern Hemisphere, FUCHS) to ·79 (Mexico), the average value being ·24.

In fifteen cases the amplitude of the semi-annual period is greater than that of the annual period, and in three others the amplitudes are equal; the amplitude of the annual period in the former cases ranging from ·05 to ·43, on an average being ·19. It is worthy of notice that different catalogues for the same district generally agree in this respect; especially is this the case with the Balkan Peninsula, Zante, and the south-east of Europe, and in New Zealand.

Moreover, eleven of these fifteen records include the following insular districts, which are among the most well-marked seismic regions in the world, namely, the Grecian Archipelago, Japan, the Malay Archipelago, New Zealand, and the West Indies. The average amplitude of the annual period in these cases is ·16, and that of the semi-annual period ·24; that is, the average amplitude of the annual period is just half that of all the districts examined, while, in the case of the semi-annual period, the two average amplitudes are exactly the same.*

ORIGIN OF THE ANNUAL SEISMIC PERIOD.

87. The most probable theory of the origin of the majority of non-volcanic earthquakes is that they are due to the impulsive friction occasioned by the slips which are the elements in the growth of faults. These slips are due, in the first instance, to endogenic causes, and, were there no external phenomena of a periodic nature to affect them, would take place equally at all times of the year.

In nearly every part of the world, however, there is a well-marked annual barometric period, the maximum epoch over the land-areas being somewhat variable, but occurring as a rule during winter. The range, or double amplitude, is small, the maximum being about one inch, and in some districts less than one-tenth of an inch.

The distortion of the earth's surface by parallel waves of barometric elevation and depression has been investigated by Professor G. H. DARWIN.† The vertical displacement is

$$\frac{gwh}{2v} b \left(1 + \frac{x}{b}\right) e^{-x/b} \cos \frac{z}{b},$$

where the axis of x is vertically downwards and the axis of z horizontal and perpendicular to the barometric undulations, g gravity, v the modulus of rigidity, w the

* This phenomenon shows that the annual and semi-annual periods must have entirely different origins.

† "On Variations in the Vertical due to Elasticity of the Earth's Surface," 'Brit. Assoc. Report,' 1882, pp. 106–119; 'Phil. Mag.,' vol. 14, 1882, pp. 409–427.

specific gravity of mercury, h the maximum range of the barometer, and $2\pi b$ the wave-length of the barometric undulation. To obtain an estimate of the maximum displacement at the surface, namely, $gwhb/2v$, Professor DARWIN takes $w = 13{\cdot}6$, $h = 5$ centims., $2\pi b = 5000$ miles $= 4{\cdot}8 \times 10^8$ centims., nearly, and $v/g = 3 \times 10^8$, which is equivalent to assuming that the superficial layers of the earth are more rigid than the most rigid glass. With these data he finds the maximum displacement of the surface to be $4{\cdot}5$ centims., so that the ground is 9 centims. higher under the barometric depression than under the elevation.

The ratio of the vertical displacement at depth x to that at the surface is

$$(1 + x/b)\, e^{-x/b},$$

or

$$1 - x^2/2b^2 + x^3/3b^3.$$

Thus, the displacement at first diminishes very slowly as the depth increases, and is independent of the modulus of rigidity and the barometric range; being, with the above value of b, only one-fifth per cent. less at a depth of fifty miles than it is at the surface.

Now, since most or all earthquakes probably originate at a depth much less than this, and since the fault-slip which produces even a moderately strong shock must be very small, for even in the most violent earthquakes it is rarely perceptible at the surface; also, since the work to be done is, not the compression of solid rock, but the slight depression of a fractured mass of rock whose support is very nearly, but not quite, withdrawn; on these accounts it seems possible that the annual variation in barometric pressure may be competent to produce the annual variation in seismic frequency.

It is not to be expected that the amplitude of the annual seismic period in different districts should be proportional to that of the annual barometric period; but if there is a connection between the two periods the epoch of the seismic maximum should coincide with, or follow closely after, that of the barometric maximum.

88. Over the greater part of the northern hemisphere, the annual barometric maximum occurs as a rule either in November or December, except at lofty stations or in high latitudes. In Europe the maximum occurs nearly everywhere in November, except along the western border in latitudes north of about 45°, over which the Atlantic conditions prevail for some distance inland. In Asia the maximum is nearly always in December. In North America it occurs in November and December, and along part of the western coast in January.

In the seismic districts of the Southern Hemisphere, the maximum occurs as a rule in the corresponding months:—in New Zealand in April, in the south-east of Australia in May or June, in South America in June or July, with some few exceptions in each case, depending either on the altitude or neighbourhood to the

89. Comparisons between the dates of the maximum epochs of the seismic and barometric annual periods can be made in thirty-one of the districts treated in this paper. The epoch of the seismic maximum approximately coincides with that of the barometric maximum in ten districts, and follows it by about one month in nine, and by about two months in four districts. In four others (Japan, Tokio, India, California), the seismic epoch precedes the barometric by about two months; but, in the first two of these at least, this may be due to the inclusion of slight shocks having their maximum in summer. To the same cause, perhaps, may be due the four exceptional cases (Scandinavia and Iceland, Great Britain, the district round and including Vesuvius, and Sicily), though many of the Vesuvian and Sicilian earthquakes are obviously of volcanic origin, and are probably more frequent with a low barometric pressure. Thus, as a general rule, the epoch of the seismic maximum either coincides with that of the barometric maximum, or follow it by a month or two.

If the epoch of the barometric or seismic maximum were constant in either hemisphere, this general agreement might not possess much significance, but it continues when the epochs vary. For example, in the southern hemisphere, we have the following dates :—

District.	Barometric maximum.	Seismic maximum.
South-east Australia . .	May and June	May
New Zealand	April	March–May
Chili	July	August
Peru, Bolivia, and Quito .	July	July

Again, while in both North and South America the maximum epochs of both periods fall in the winter months, in the Sandwich Islands (lat. 20° N) the epoch of the seismic maximum occurs in June, and that of the barometric maximum at Honolulu in April or May.

90. Lastly, supposing the view here suggested to be correct, the annual variation in barometric pressure cannot have any influence on seismic frequency when the earthquakes originate entirely beneath the sea; for, as the barometric pressure changes, the sea will have time to take up its equilibrium position, and the total pressure on the sea-bottom will be unaltered. Hence, if some of the earthquakes felt in a district originate beneath the sea and some beneath the land, the amplitude of the annual period will be less than it would be if all were to originate underneath the land. Since some of the foci of the earthquakes felt in Japan and New Zealand are known to lie beneath the ocean, it seems not improbable that the small amplitude of the annual period in these two, as well as in other, insular districts may be thus